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Treating Liquid Manure as a Possible Source of Drinking Water for Pigs

By

Mahendran Navaratnasamy ©

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In

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The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled ***Treating Liquid Manure as a Possible Source of Drinking Water for Pigs***, submitted by Mahendran Navaratnasamy in partial fulfillment of the requirements for the degree of ***Masters of Science in Bioresource and Food Engineering***

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ABSTRACT

Addition of alum, lime and gypsum did not result in a significant reduction in total suspended solids (TSS) levels from the natural settling treatment. Mechanical aeration, ozonation and natural settling reduced total dissolved solids (TDS) levels. Aeration reduced TDS levels at a faster rate than ozone treatment (1.8 mg/L at 2.6 Lpm) and natural settling. Aeration at a rate of 3 Lpm reduced 83 % of TDS in 7 days to meet the recommended TDS level (3000 mg/L) for swine drinking water. Slow sand filtration reduced pathogens in an aerated liquid to meet the recommended level of 5000 coliform/100 ml for swine drinking water. Blending 20 % fresh water with the slow sand filtered liquid after 7 days of aeration would provide a liquid, which could be used as drinking water for pigs. The estimated energy cost for aeration was $0.20/growing pig.

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CHAPTER 1 INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Pork production has become a flourishing industry in Canada while water is becoming a scarce commodity. The large water requirements for pork production cause concern to the pork producers especially during a period of drought. Normally livestock manure contains more than 90 % of water. The remaining 10 % solids are made up of suspended and dissolved solids. Chemical addition and natural settling methods were used to separate the liquid fraction of manure from the solid fraction in this study. However, these liquid-solid separation methods can not remove the dissolved solids effectively. Therefore, aeration, ozonation and reverse osmosis treatment methods were used to reduce TDS with objective of treating the liquid fraction of manure to use as drinking water for pigs. The Canadian Water Quality Guidelines (1995) recommends that the total dissolved solids (TDS) in livestock drinking water should not exceed 3000 mg/L. When recycling liquid manure for drinking purpose after removing TDS, pathogen removal is essential to ensure safety for the animals and animal product consumers. The technology of ozonation, chlorination and ultraviolet treatment are available in the market. Slow sand filtration and ozonation technique were used to remove pathogens (fecal coliform and *e-coli*) in this study. This thesis is written in paper format. This chapter of introduction and literature review will be followed by the chapters for separating the liquid fraction from the solid fraction, for removing TDS from the liquid fraction and for conclusions and recommendations.

LITERATURE REVIEW

Literature on recycling livestock waste, liquid manure characteristics, drinking water standards for pigs and suitable treatment methods were reviewed with regard to meeting the objective of recycling liquid manure as a source of drinking water for pigs.

Recycling Livestock Manure

Manure has been recycled by applying it directly on a field crop. However, other possibilities have also been investigated. Systematic investigation of using manure as feed began in 1940 (Berk 1979). Animal wastes contain significant amounts of protein, fiber and essential minerals and have been deliberately incorporated into animal diets for their nutrient properties for almost 40 years. Recycling of animal manure as feed ingredient is primarily a local practice. Food and Drug administration (FDA) in USA has a policy not to take an active surveillance role in regulating the use of processed animal manure as a feed ingredient (FDA 1995). Although not officially recognized by FDA, Association of American Feed Control Officials (AAFCO) has published model regulations for processed animal feed for commercial use which, FDA expects every state to follow (FDA 1995). AAFCO recommends that all recycled animals feed products be assayed *for Salmonella, Ecoli* bacteria and heavy metals. Guidelines for recycling animal waste as feed ingredients are useful as no guidelines exist for recycling liquid fraction of swine manure for drinking purpose. Literature has indicated that the liquid portion of the swine manure can be separated, treated and recycled for flushing or irrigation purposes (Overcash et al.1983). A private company has used ozone to purify hog farm wastewater and suggested that the treated water can be used for drinking purposes (Agrimond 2000).

Swine Manure Characteristics

The characteristics of swine manure are a function of digestibility and composition of feed rations. The swine manure is chiefly made up of undigested food, and is mostly cellulose fiber. Undigested protein is normally excreted in the urine as urea. Manure contains, digestive fluids, waste mineral water, worn out cells from the intestinal linings, mucus, bacteria and foreign matter such as dirt consumed along with the food (Dewi et al. 1994). Collected and stored manure also contains feed spilled in the animal pen. The amount of water in the liquid manure varies depending on the usage and drinking water spillage. According to the report submitted by Bayne (1998), the moisture content in the liquid manure varies from 90 to 98%. Fresh manure production and characteristics according to ASAE (1997) are shown in Table 1.1.

Table 1.1 Fresh swine manure production and characteristics per 1000 kg live animal mass per day (ASAE 1997).

Parameter	Unit	Amount
Total manure	kg	84
Urine	kg	39
Density	kg/m^3	990
Total solids	kg	11
BOD, 5 day	kg	3.1
COD	kg	8.4
pH		7.5
Total Kjeldahl nitrogen	kg	0.52
Ammonia nitrogen	kg	0.29
Total phosphorus	kg	0.18
Ortho phosphorus	kg	0.12
Potassium	kg	0.29
Calcium	kg	0.33
Magnesium	kg	0.070
Sulfur	kg	0.076
Sodium	kg	0.067
Chloride	kg	0.26
Iron	g	16
Manganese	g	1.9
Boron	g	3.1
Molybdenum	g	0.028
Zinc	g	5.0
Copper	g	1.2
Cadmium	g	0.027
Nickel	g	
Lead	g	0.084
Total coliform bacteria	Colonies*	45
Fecal coliform bacteria	Colonies*	18

* Mean bacteria colonies per 1000 kg animal mass multiplied by 10^{10}.

According to the data from the Table 1.1, fresh manure has a moisture content of 91.1 %, and total solids of 8.9 % mass (wet basis). Fresh manure has valuable nutrients. Further analysis shows that swine manure has 4.7% nitrogen, 1.6% total phosphorous and 2.6% potassium by mass (dry basis). Heavy metals cause concerns when recycling manure as drinking water and feed ingredients. From the data in Table 1.1, total heavy

metals are 0.25 % by mass (dry basis) in the manure. Coliform bacteria are also present in large numbers in the fresh manure in the order of 10^{10}.

Drinking Water Standards

Table 1.2 Drinking Water Parameter Standards for Pigs

Parameter	Acceptable limits	Units	Reference
pH	6.5 to 8.5		PPRG (2000)
TDS	3000	mg/L	Coote (2000)
Alkalinity	5000	mg/L	Coote (2000)
Hardness	Not established	mg/L	Coote (2000)
Calcium	1000	mg/L	CWQG(1995)
Sodium	500	mg/L	PPRG (2000)
Sulfate	750	mg/L	PPRG (2000)
Nitrite-Nitrate N	100	mg/L	PPRG (2000)
Iron	0.3	mg/L	PPRG (2000)
Aluminum	5.0	mg/L	CWQG(1995)
Arsenic	0.5	mg/L	CWQG(1995)
Berylium	0.1	mg/L	CWQG(1995)
Boron	5.0	mg/L	CWQG(1995)
Cadmium	0.02	mg/L	CWQG(1995)
Chromium	1.0	mg/L	CWQG(1995)
Cobalt	1.0	mg/L	CWQG(1995)
Copper	5.0	mg/L	CWQG(1995)
Fluoride	1.0	mg/L	CWQG(1995)
Lead	0.1	mg/L	CWQG(1995)
Manganese	N/A	mg/L	CWQG(1995)
Mercury	0.003	mg/L	CWQG(1995)
Molybdenum	0.5	mg/L	CWQG(1995)
Nickel	1.0	mg/L	CWQG(1995)
Selenium	0.05	mg/L	CWQG(1995)
Uranium	0.2	mg/L	CWQG(1995)
Vanadium	0.1	mg/L	CWQG(1995)
Zinc	50	mg/L	CWQG(1995)

Drinking water of good quality is essential for livestock. Poor quality water causes loss in production, suppresses appetite and leads to inferior product quality. Water quality is

determined by analyzing chemical and biological parameters. Chemical parameters for animal drinking water are shown in Table 1.2. Total dissolved solids (TDS) are the sum of all dissolved organic and inorganic material present in the water. Therefore, reducing TDS would purify the water. According to the Pork Production Reference Guide (PPRG 2000), TDS should be less than 1500 mg/L for drinking water for pigs. However, this limit can be exceeded depending on the minerals that TDS consists of. According to Canadian water quality guidelines (CWQG 1995), 3000-mg/L of TDS level is suitable for all classes of livestock drinking water provided that the salinity level is less than 1000 mg/L. In treating liquid swine manure as a drinking water source, the realistic target TDS level can be 3000 mg/L, since liquid manure has a high level of TDS which is made up of organic matter mostly and reducing the TDS concentration levels to 1500 mg/L would be more expensive. Microbial contamination causes serious concern for the livestock industry. Number of pathogens and parasites can be transmitted to water from the contamination of manure. The most common and serious microbial contaminants in the pork industry are from *Salmonella* and *Escherichia coli (E-coli)*. The CWQG (1995) does not give any specific standard for pathogens and parasites. However, PPRG (2000) recommends maximum monthly mean of 5000 coliform/100 ml as a guideline.

Treatment Methods

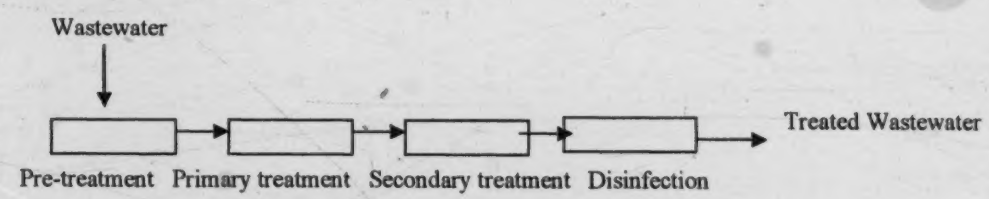

Figure 1.1 Schematic diagram of typical waste treatment system

Typical wastewater treatment system (Figure 1.1) consists of treatment units such as pretreatment, primary treatment, secondary treatment and a disinfection unit. Screen mesh is used in pretreatment to remove large floating particles. Usually gravity settling is used as primary treatment where suspended and heavier particles are settled and separated. The secondary treatment in wastewater treatment is one of the biological treatment systems. Aerated lagoons, activated sludge, trickling filters and rotating biological contactors are the most common biological treatment systems. In secondary treatment, cell mass is encouraged to grow under aerobic conditions and separated by settling. Separating the cell mass in the secondary treatment is known as clarification. Secondary treatment systems can be broadly categorized based on the type of cell growth as follows:

1) suspended growth
2) attached growth, and
3) dual suspended and attached growth.

The clarified wastewater from a secondary treatment is further treated to remove harmful microorganisms by using chlorination, ozonation or UV disinfection methods. The number of treatment units or methods needed for a treatment scheme depends on the influent quality and desired effluent quality. Literature on treatment methods such as liquid-solid separation, slow sand filtration, membrane filtration, aeration and ozonation were reviewed in the following sections with the objective of assessing their applicability to recycle liquid manure as a source of drinking water for pigs.

Liquid-solid Separation

Liquid-solid separation methods are used to separate the liquid fraction of the swine manure stream to recharge the manure gutters, reduce the organic concentration in the liquid fraction, increase the nutrients in the solid fraction, make transport and handling easier and possibly reduce odour. Liquid-solid separation is usually achieved by screening, centrifuging and gravity settling. Screening removes large floating particles. Eventhough centrifuging is an effective liquid-solid separation method, centrifuging is not commonly used in wastewater treatment since it is expensive. Gravity settling is very effective in manure streams with less than 1 % solids (Bicudo 1995). According to Fleming (1986), liquid manure usually contains around 3 to 6 % solids. The ratio of solid to liquid can be easily reduced by adding water. Shallow and wide sedimentation basins with flow velocity of less than 0.3 m/s are used for liquid-solid separation (Mukthar et al. 1999). Retention time of 20 to 30 min is desired for settling liquid manure (Mukthar et al. 1999). The recommended maximum period for storage is 10 days, since after 10 days suspended solids tend to decompose at faster rate (Zhu et al. 2000). Chemicals can be added to enhance the liquid-solid separation. Aluminum sulfate (Alum) and ferric chloride are effective coagulants to enhance settling rate (Zhang and Lei 1998). Zhang and Lei also recommended keeping the solid level about 1% for better coagulation. Worley et al. (2000) said that addition (0.5 % by volume) of alum increased the separation efficiency from 60 to 70 %. Eikebrokk (1999) reported that 75 to 90 % of natural organics can be removed from humic waters by using alum ($Al_2 (SO_4)_3.18 H_2O$ and poly aluminum chloride (p-$AlCL_3$). Chow et al. (1999) found out that the low molecular weight organic substances were not removed easily by addition of alum when

comparing to the higher molecular weight organic matters. Cecen et al. (2000) reported that Lime [Ca (OH) $_2$] precipitates heavy metal more effectively than alum. Charentanyarak (1999) reported that the optimum pH for lime precipitation is 9.5.

Aeration

In the aeration processes, microorganisms metabolize waste when oxygen is continuously available. This process is associated with very little or no odour. When oxygen is supplied continuously, organic waste is converted to carbon dioxide, water and microbial cell mass. Two common ways of aeration are available. They are natural and mechanical aeration. Natural aeration lagoons do not provide dischargeable effluent and odour control (Overcash et al. 1983). Mechanically aerated lagoons can provide positive odour control when properly designed and managed. High amounts of energy are needed for complete removal of organic matter. However partial aeration will be able to provide sufficient odour control (Fleming 1986). In aerobic treatment, aerobic bacteria use the dissolved and suspended organic matter as a source of energy to produce cell mass. Aerating pig slurry with 3 % suspended solids for 168 hours resulted in 71% and 40 % reduction in chemical oxygen demand (COD) and total suspended solids, respectively (Doyle 1987). Jern (1987) found that the suspended solid removal after aeration is very poor by settling, which results in excess of cell mass. The aerobic process produces more cell mass than anaerobic process. In the aerobic process 50% of the carbon is converted into cell mass.

According to literature, aeration can reduce pathogens. Burton (1992) reported that aeration could be used to reduce pathogens in pig slurry. Bicudo et al. (1995)

reported that even though intermittent aeration reduces the bacterial concentration, the fecal and streptococci coliform bacteria were found in the order of 10^6. Munch et al. (1987) studied the survival of *E-coli* and *streoptococci* and reported that pathogen count in the aerated slurry was less than the non aerated slurry and still very high. Chlorination and ozonation reactions remove pathogens by oxidizing them. As dissolved oxygen level in the aerated liquid has some oxidizing capacity, pathogens may be reduced during aeration.

Aeration is an attractive alternative to reduce both odour and the presence of ammonia and hydrogen sulfide. Burton (1992) also found that 1 to 2 days of aeration produces sufficient odour control if the slurry is to be disposed within a few days and three to five days aeration can produce sufficient odour control for storing the slurry up to six weeks. Odour is due to volatile organic compounds resulting from the microbial degrading of fecal residues. Aerobic treatment rapidly oxidizes most odourant compounds and produces a mild earthy odour (Evans 1985).

Membrane Filtration

Reverse osmosis, micro filtration, ultra filtration and electro dialysis are known as material separation processes using membrane technology. By using these methods dissolved substances or finely dispersed particles can be separated from liquids (Cheremisinoff 1995). Reverse osmosis membranes are capable of removing at least 90 % of the dissolved solids as well as organics, bacteria and some other impurities (Cheremisinoff 1995). Osmotic pressure increases with the increase in the concentration of soluble materials in the water. For dimineralizing 35,000 ppm of NaCl in water, 2744 kPa osmotic pressure is needed while for dimineralizing 1000 ppm of NaCl in water, 542

kPa of osmotic pressure is sufficient (Cheremisinoff 1995). Reverse osmosis is a solubilization diffusion technique whereas micro and ultra filtration traps particles of the size more than that of the membrane pore sizes. Size of dissolved solids is of the order of 10^{-7} mm (Kiely 1998). Therefore, micro and ultra filtration may not remove dissolved solids since the membrane pore sizes are less than 10^{-7} mm and so the reverse osmosis method is most suitable for total dissolved solids (TDS) removal. Table 1.3 shows the filtration methods and their pore sizes. The most common problems in using membrane technology are membrane scaling, membrane fouling by metal oxides, plugging, colloidal fouling and biological fouling. Natural settling followed by sieving followed by micro filtration followed by reverse osmosis produced volume reduction of 77 % of raw pig slurry leaving 23 % of sludge (Pieters et al. 1999). This system costs $ 13.20 /m^3 of raw slurry.

Table1.3 Filtration methods and pore sizes (Kiely 1998)

Method	**Range in mm**
Conventional filtration	10^{-1} -10^{-2}
Micro filtration	10^{-2} -10^{-4}
Ultra filtration	10^{-4} -10^{-6}
Reverse Osmosis	10^{-6} -10^{-7}

Ozonation

Ozone is sometimes used in wastewater treatment plants for disinfection purposes. Ozone also oxidizes the organic material found in the wastewater and reduces the bio-chemical oxygen demand (BOD) and chemical oxygen demand (COD) forming organic intermediates and end products. A disinfectant of 3-10 mg/L in gaseous phase is common (Cheremisinoff 1995) in wastewater treatment. A concentration of 15-32-mg/L of ozone in gaseous phase provided sufficient reduction in fecal coliform (1000 CFU/100mL) to reuse the ozonated water for agricultural purposes (Liberti 1999). The malodorous bacterial metabolites (phenol, p-cresol, p-ethyl-phenol etc.) were found eliminated after ozone treatment and the odour intensity is reduced at 0.5 g/l of ozone dosage (Wu and Park 1999). This slurry did not regain its original offensive odour intensity after a month-storage subsequent to the ozone treatment which, is due to the elimination of malodor metabolites.

Slow Sand Filter

Slow sand filtration is commonly used to remove suspended solids from wastewater. Particle removal mostly happens at the surface of the sand bed. A layer of retained solids develops at the top of the sand bed. Organic matter that settles on the top of the sand bed could filter disease-causing organisms including *Giardia cysts* and *Cryptosporidium oocytes*. A layer of trapped organics on the surface of a filter can also act as a biofilter. A slow sand filter is very effective and economical method to remove the suspended particles in water or wastewater treatment systems. The depth of sand filter

is normally from 0.5 m to 1.5 m and the size of the fine sand is 0.15 to 0.35 mm (Barth 1996). The filtration speed is about 0.1 – 0.2 m/h (Logsdon 1991).

CONCLUDING REMARKS

From the literature review, treatment methods such as chemical addition, and natural settling for liquid-solid separation, aeration, ozonation and reverse osmosis for TDS removal and slow sand filtration and ozonation for pathogen removal appear to be promising to meet the objective of recycling liquid manure as drinking water for pigs. Experiments were carried out and results were discussed in the following chapters by using these treatment methods.

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CHAPTER 2 SEPARATING THE LIQUID FRACTION OF SWINE MANURE

INTRODUCTION

Pork production is a growing industry in Canada. Pork production requires large amounts of water which is a cause of concern to pork producers. Pork production also generates large amount of manure which is associated with many concerns to the pork producers and public. Swine manure is often made up of more than 90 % water. Separating the liquid fraction of swine manure is desirable because of the following:

1. Recycle liquid fraction for charging manure storage gutters,
2. Reduce organic fraction in the liquid fraction,
3. Concentrate nutrients in the solid fraction,
4. For easier handling and transportation, and
5. Possibly to reduce odour.

In municipal water and wastewater treatment systems, coagulants are added to enhance liquid-solid separation. Alum $\{Al_2(SO_4)_3.18\ H_2O\}$ is the most commonly used coagulant in the water and wastewater treatment processes. The chemical reaction of alum is as follows:

$$Al_2(SO_4)_3.18\ H_2O + 6HCO_3^- \text{------- } 2Al(OH)_3\downarrow + 6CO_2 + 18H_2O + 3SO_4^{2-} \quad \ldots\ldots 2.1$$

When alum is added to wastewater positively charged aluminum ions (Al^{3+}) are produced. Some of the positively charged ions neutralize the water and make the colloidal particles adhere with each other. These heavier particles can be settled and separated from the liquid fraction easily. However, most of the aluminum ion reacts with

alkalinity in wastewater (bicarbonate) to form aluminum hydroxide, which also adsorbs ions from the solution and forms precipitate of aluminum hydroxide (Kiely,1998). Lime is also used as a coagulant. Lime is usually used to precipitate calcium, magnesium and some heavy metals from the wastewater (Cecen 2000). When lime is added to wastewater, pH of the wastewater is raised converting soluble bicarbonate ions into insoluble carbonates. Lime addition can also precipitate some of the toxic metals and phosphorous. Therefore, addition of lime can reduce total dissolved solids (TDS) levels to some extent. Culp (1978) claimed that the addition of lime can reduce 10 –15 % of TDS levels. Gypsum is cheap and in abundant supply in Canada. Gypsum is used as soil amendment in agriculture where sulfur is deficient. Gypsum is also reportedly used in fishponds for clarification by adding to the water (www.perigee.net..., agfacts.tamu.edu...). Natural settling is an economically less expensive method used in livestock manure handling facilities to separate the liquid fraction. Natural settling is usually accomplished in a series of settling tanks or ponds. However, removal of fine particles and dissolved solids need further treatments.

OBJECTIVE

1. To compare the total suspended solids (TSS) levels in the supernatant liquid after chemicals treatments and natural settling treatment.

2. To study the effects of chemicals additions on total dissolved solids (TDS) levels and sulfate levels with the objective of treating the liquid fraction of the manure as a possible source of drinking water for pigs.

MATERIALS AND METHODS

Alum, gypsum and lime were used to study their effectiveness in promoting settling compared with natural settling as a control. The alum and lime are laboratory grade. The gypsum used was waste crushed wallboard gypsum. Two different concentrations were chosen for alum, lime and gypsum based on the preliminary experiments. The two different concentrations of gypsum were added to alum and lime treatments. Therefore, the total number of treatments was nine including the controls (Table 2.1). Each experiment was repeated 7 times. Liquid swine manure was collected from the Edmonton Research Station Swine Research center and stored in a cold room at 4^0 C. Chemical characteristics of raw swine manure is shown in appendix 2. Nine cylindrical jars with capacity of 2 L were used. Each jar was filled to the 2000-mL level with liquid swine manure. Chemicals were added to all jars except the controls and stirred well (manually). After stirring, each jar was left undisturbed for a period of 24-h. After settling, the supernatant water was slowly siphoned off into a 500-mL container and sent to a laboratory (AFNS, University of Alberta) for analysis of total suspended solids. Total suspended solids were analyzed according to Standards Methods (Eaton et al., 1995).

As a separate experiment, 250 mg/L of alum was added to 10 L of manure, mixed well (manually) and allowed to settle for a day. Supernatant liquid was passed through a slow sand filter. The height and diameter of the sand media is 0.3 m and 0.05 m, respectively. Play ground sand was used as filter media. The average size of the sand is 0.27 mm. Samples from raw manure and filtered liquid after alum addition were analyzed

(Eaton et al., 1995) to find TDS and sulfate concentrations for comparison (Table 2.2). This experiment was not repeated.

Addition of 250 mg/L and 500 mg/L of alum produced flocs that were visible during the previous experiments carried out for TSS comparison. Therefore, trial and error method was used to find the alum requirements for effective liquid solid separation. Alum concentration levels of 2000 mg/L and 3000 mg/L separated the liquid and solid into two layers in 500-ml beakers. The coagulated solids were in the upper layer where as a relatively clear liquid was in the lower layer. The separated liquid fraction was like murky water. Higher alum concentrations produced clearer liquid. A period of 24-h was allowed before siphoning off the liquid from the beakers. The TDS concentration levels were obtained by using a conductivity meter (Model 50150, Loveland, CO) and the results were discussed in the following sections (Figure 2.1). This experiment was repeated 3 times.

A preliminary experiment was also carried out in which 5000 mg/L of lime and 5000 mg/L of gypsum were added separately and in combination to three containers of 2000-ml liquid manure. After adding the chemicals, the liquid manure was stirred and settled for two weeks. After two weeks supernatant water was siphoned off and analyzed for TDS and sulfate levels. These values are shown in table 2.3. This experiment was carried out just one time.

Statistical Model

Statistical Model $TSS_{ijk} = \mu + T_i + S_j + \varepsilon_{ijk}$

TSS- total suspended solids (mg/L),
μ - mean,
T_i - treatment,
S_j - set, and
ε_{ijk} . natural error term.

Analysis of variance (ANOVA), one way classification was used to compare the TSS values obtained for each treatment by using SAS computer software. One way classification is a simple analysis to compare the means of treatments. It was assumed that there were no interactions between treatments and sets. Each set of experiments was repeated 7 times.

RESULTS AND DISCUSSION

There was no significant difference among the treatments (P>0.05). The mean TSS value of each treatment is given below (Table 2.1). TSS values of each treatment which was repeated 7 times were shown in the Appendix 1. The coefficient of variance (CV) is 50 %.

Table 2.1 Mean TSS values for chemical and natural settling

Treatment	Chemicals Concentration (mg/L)	Mean TSS (mg/L)	CV %
1	Alum (250)	160	50
2	Alum (500)	160	50
3	Alum (250)	193	50
	Gypsum (500)		
4	Alum (250)	172	50
	Gypsum (1000)		
5	Lime (3000)	173	50
6	Lime (4500)	153	50
7	Lime (3000)	162	50
	Gypsum (500)		
8	Lime (3000)	261	50
	Gypsum (1000)		
9	Controls	162	50

Alum

Dosage of alum of 250 mg/L and 500 mg/L did not produce enough coagulation to separate the solid fraction from the liquid fraction by gravity settling even though these additions produced flocs which were visible. Mean TSS values of the control and alum treatment were almost the same ($P>0.05$). Therefore, addition of 250 mg/L and 500 mg/L of alum did not provide effective settling.

Table 2.2 TDS and sulfate concentration after adding 250 ppm of alum

Parameter	Liquid Manure (ppm)	After Adding Alum (ppm)
TDS	4160	4020
Sulfate	370	470

Table (2.2) shows the result of a supernatant liquid which was passed through a slow sand filter after adding 250 mg/L of alum. The results (Table 2.2) show a slight reduction in TDS and increase in the sulfate concentrations after adding alum. As carbonates, sulfates, chlorides, etc. of sodium, calcium and magnesium contribute to TDS, a reduction in bicarbonates and adsorption of organic and inorganic materials by aluminum hydroxide precipitate would result in TDS reduction. Equation (2.1) shows that addition of alum results in addition of sulfate in the supernatant liquid. Liquid manure contained considerable amount of organic and inorganic substance in dissolved and suspended forms. Therefore, the concentration of alum (250 mg/L) added was not sufficient to separate solids adequately from the liquid manure and provide a clear liquid.

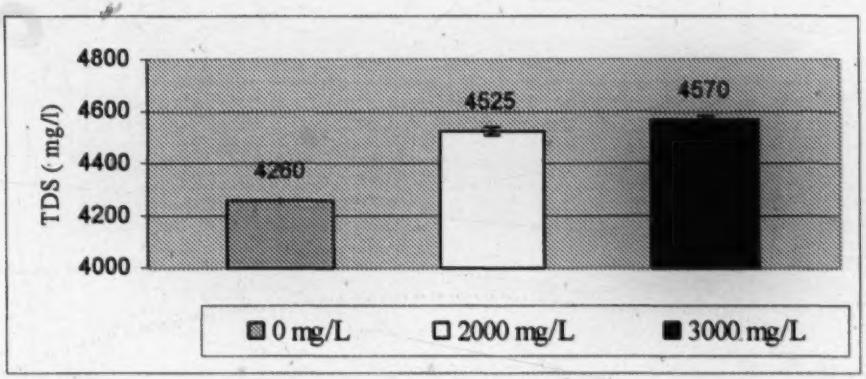

Figure 2.1. TDS of clear water after 2000 and 3000 mg/L of alum addition

Addition of higher concentrations (2000-mg/L and 3000-mg/L) of alum separated liquid from the solid fraction. 3000-mg/L of alum produced clearer liquid than 2000-mg/L of alum. However, both the separated liquid was like murky water. Figure 2.1 shows the values of TDS in the liquid fraction of swine manure after adding 2000-mg/L and 3000-mg/L of alum. Addition of alum at concentration levels of 2000 mg/L or 3000 mg/L increased the TDS from 4260 to 4525 and 4570 mg/L, respectively as shown in Figure 2.1. This increase in the TDS levels were due to the presence of dissolved aluminum and sulfate ions in the separated liquid fraction. Animal drinking water standards recommend that the presence of maximum amount of aluminum is 5.0 mg/L (CWQG 1995). If it is assumed that all the above TDS level increase was due to the dissolved alum in the liquid, the aluminum concentration in the liquid would exceed the drinking water standard by 8 and 10 times for 2000-mg/L and 3000-mg/L, respectively. However, no evidence has been reco...d to prove that the aluminum ion concentration higher than 5.0 mg/L in drinking water would be harmful to pigs. High aluminum content in sludge is also a concern. Arnold et al. (1994) said that 0.00958 kg/m^2 was the recommended limits for aluminum sludge application. However, the leachable aluminum

content in the bio-solids should not exceed 0.2 mg/L according to the ASTM standards (Arnold et al.1994). Chemical analysis further showed that the raw manure used in this experiment had 788 mg/L of sulfate, which was also more than the recommended level for pig drinking water (PPRG 2000). Addition of alum increases sulfate concentration. Therefore, further treatment would have been required to tackle the presence of excess of aluminum and sulfate ions in the supernatant water when high dosage of alum had been used. Alum addition could be expensive too. Addition of 2000 mg/L and 3000 mg/L of alum costs $ 1.01 and 1.51 per growing pig, respectively when assuming that pigs drink water 4 L/d and their growth cycle is 100 d. The least cost for alum was quoted as $ 1.25/ kg without delivery and taxes (www.beckart ...). There is a possibility that this expense may be reduced by recycling the alum sludge. However, recycling the alum sludge was not carried out in this study.

Lime

Table 2.3 TDS and sulfate concentrations after adding lime and gypsum and settled for two weeks.

Parameter	Lime (5000 mg/L)	Gypsum (5000 mg/L)	Lime/Gypsum (5000 & 5000 mg/L)	Natural Settling (mg/L)
TDS	3790	6220	4990	5130
Sulfate	130	1980	1370	172

A concentration of 3000-mg/L and 4500-mg/L of lime did not result in significant reduction of suspended particles (Table 2.1). The supernatant water was very unclear indicating the presence of dissolved and suspended organic and inorganic matter.

Mean TSS values of lime additions made little difference compared to the control. Table 2.3 shows the results obtained during a preliminary experiment which indicates that the TDS concentration level was reduced after adding lime. Lime addition settled some carbonates and metal hydroxides (Culp 1978). The reduction of carbonates and metal hydroxides would have reduced the TDS in the liquid fraction. Sulfate concentration was also reduced (Table 2.3). In this experiment settling was carried out for a period of 2 weeks. This long-period- settling would have separated some of the sulfate containing organic matter from the liquid fraction. Eventhough lime addition reduced TDS and sulfate concentration, lime addition did not separate the organic solids from the liquid as the higher concentration of alum did.

Gypsum

Addition of gypsum 500 mg/L and 1000 mg/L along with alum and lime did not significantly influence the settling effectiveness. In fact, treatments 3, 4 & 8 show higher TSS mean values than the controls (Table 2.1). This may be due to the fact that some of the added gypsum was in suspension. The chemical formula of gypsum is $CaSO_4.2H_2O$. Gypsum is basically resistant to chemical reaction and partly soluble in water (Douglas 1984). In this experiment, as the gypsum was dissolved in water, sulfate and TDS concentrations in the supernatant water were increased, which is shown in Table 2.3. Addition of lime and gypsum in combination had better TDS reduction than natural settling due to the coagulating and settling properties of lime. Sulfate concentration in the lime-gypsum combination was less than that of the gypsum addition alone. Addition of gypsum along with alum and lime did not separate solids more effectively than adding

alum or lime alone. In a preliminary experiment, a high dosage (5000 mg/L) of gypsum and lime were added. However, in the subsequent experiment gypsum had been added in combination with alum and lime to find if the combination worked better. The addition of gypsum alone and in combination with alum and lime was not effective in settling the solids in the liquid manure (Figure 2.3).

Natural Settling

Natural settling depends on the size and density of particles. In this experiment the control was natural settling, which did not make any significant difference with the other chemical treatment. Natural settling is common and cost effective way to reduce the suspended solid levels in the swine manure. Natural settling is capable of reducing biological oxygen demand (BOD) by 35 % and suspended solids by 60 % (Cheremisinoff,1995). Recommended retention time for gravity settling is usually from 20 to 30 min for swine manure (Mukthar et al.1999). During this time most of the heavier particles would settle. Eventhough settling efficiency is increased with the increasing retention time, the increase in the efficiency of settling would be increasingly less due to slow settling of very fine particles. Further, increasing the retention time would need bigger liquid manure storage tanks which would be more expensive. Therefore, a 24-h period of retention of liquid manure in this experiment was considered to be sufficient.

CONCLUDING REMARKS

Eventhough addition of 250 mg/L and 500 mg/L of alum produced visible flocs, they did not reduce TSS significantly more than natural settling. Addition of higher

amount of alum as much as 2000 mg/L and 3000 mg/L satisfactorily separated the solids from the liquid. Adding 3000 mg/L of alum resulted in better separation than adding 2000 mg/L. However, presence of organic matter was visible in the separated liquid after adding 3000 mg/L of alum. Addition of 250 mg/L of alum increased the sulfate concentration in the supernatant liquid. Therefore, adding high amounts of alum would have increased the sulfate concentration more than the recommended level. Adding higher concentrations of alum increased the TDS in the separated liquid. This indicated the possibility of higher dissolved aluminum concentration in the separated liquid. Therefore, adding alum as much as 250 mg/L and 500 mg/L of alum did not reduce TSS significantly whereas adding higher alum concentration would require further treatments to tackle higher alum and sulfate concentrations. The cost of adding 2000 mg/L and 3000 mg/L of alum were $1.01 and 1.51 per growing pig, respectively, which appears expensive.

Addition of lime did not produce significantly more TSS reduction than natural settling. However, addition of lime reduced TDS and sulfate concentration by converting soluble bicarbonates and some heavy metals into insoluble carbonate and hydroxide precipitation. Even though lime reduced TDS and sulfate concentrations in the supernatant liquid, lime at high concentrations as high as 5000 mg/L did not result in significant liquid-solid separation.

Addition of gypsum did not significantly reduce TSS more than natural settling. Addition of gypsum in fact increased the TSS due to the undissolved gypsum in suspension. Addition of gypsum increased sulfate and TDS concentrations. Being

chemically inert and relatively insoluble in water, gypsum did not separate the solids from the liquid

Since alum, lime and gypsum addition did not produce satisfactory results with regard to settling and meeting the objective of recycling liquid manure as drinking water for pigs, natural settling, which is economical, was considered as the most suitable liquid -solid separation method.

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CHAPTER 3 REDUCING THE TOTAL DISSOLVED SOLIDS (TDS) CONCENTRATION LEVELS IN THE LIQUID FRACTION OF SWINE MANURE

INTRODUCTION

Pork production has become a flourishing industry in Canada while water is becoming a scarce commodity. The large water requirements for pork production cause concern to the pork producers especially during a period of drought. Therefore, recycling liquid portion of the manure would provide a method to conserve water. As swine manure contains moisture and solids, it can be divided into two fractions. They are the liquid and solid fraction. The water content in the liquid manure varies from 90 to 98% (Bayne 1998). Natural settling (Gravity Settling) is the most common method to separate liquid fraction from the solid fraction. The solid fraction is made up of organic and inorganic contents. After liquid-solid separation, most of the solids in the liquid fraction are in a dissolved form. Total-dissolved-solids (TDS) is a measure of inorganic and organic contents present in the water. Liquid fraction of the manure is mostly made up of organic matter. Experiments were carried out to remove the TDS in the liquid fraction of manure by using the following methods.

1. Aeration
2. Ozonation
3. Natural settling
4. Reverse Osmosis

Aeration is a common industrial waste treatment method used to enhance biodegradation which is a natural process where microorganisms' metabolize dissolved and suspended organic matter into stable cell mass. As the liquid fraction of manure is mostly made up of suspended and dissolved organic matter, aeration process can reduce TDS concentration levels by converting the dissolved organic matter into stable cell mass. The cell mass formed during an aeration process can be settled and removed easily. Aeration process can be categorized as natural and mechanical aeration. Mechanical aeration is an energy intensive process and associated with very little or no odour. Whereas, natural aeration needs huge tanks and associated with odour problems. Further, natural aeration does not provide a dischargeable effluent, as anaerobic condition exists at the bottom of the tanks or lagoons in most of the cases (Overcash 1983). Therefore, mechanical aeration processes are desired in industrial waste management. Ozone treatment was also used in this experiment to reduce TDS. Ozone is a powerful oxidant used in industrial water and wastewater treatment plants mainly for disinfection purposes. Being a powerful oxidant, ozone can oxidize dissolved organic matter quickly to reduce TDS levels and convert them into unknown intermediate products while killing harmful pathogens.

Membrane technology is very popular for removing TDS in water treatment processes. Reverse osmosis (RO) is an advanced unit operation in water treatment which uses membrane technology. RO is widely used to remove salinity from sea water before using the treated sea water for drinking purposes (Belfort 1984). RO membranes are known for removing more than 90 % of the total dissolved solids in water treatment processes (Cheremisinoff 1995). RO has also found application opportunities in waste

treatment, chemical separation and food and drug processes. The RO mechanism is explained as follows: Diffusion of solvent from a less concentrated solution to a more concentrated solution through a semi-permeable membrane is referred to as osmosis. Increasing the pressure adequately on the higher concentrated solution can stop the transfer of solvent. If a pure solvent is on one side of the membrane, the pressure required to equalize the solvent activities on the concentrated solution side is referred to as osmotic pressure (Belfort 1984). If the applied pressure is above the osmotic pressure, the solvent will diffuse from the concentrated solution side to the less concentrated solution side. This phenomenon is referred to as reverse osmosis, since the solvent flow is opposite to the osmotic flow. The solute removal by RO membrane also depends on the molecular weight and size. Around 90 % solute rejection was found for the compounds with molecular weight 150 by using TFC membrane made by aromatic polyamide (Ozaki 2002) when operated at a pressure range of (0.2-0.9) mPa

OBJECTIVE

1. To reduce total dissolved solids (TDS) levels in the liquid fraction of manure by using aeration, \ozonation, natural settling and reverse osmosis treatment methods with the objective of recycling liquid fraction of swine manure as a possible source of drinking water for pigs.
2. To recommend an appropriate period of treatments to reduce TDS
3. To recommend a large scale unit for the appropriate period of treatment to reduce TDS and estimate cost

MATERIALS AND METHODS

Four containers of 10-L capacity were numbered from 1 to 4. Two sets of ceramic air diffusers (Petshop, Edmonton, AB) were connected to two air pumps (Gilian Instrument Corp, W.Caldwell, NJ) and each of them were placed at the bottom of containers 1 and 2. Each set of diffusers were made up of two individual diffusers with a diameter of 1 cm and length of 2.5 cm. The ceramic air diffusers used in this experiment were sold to be used in fish tanks. Another set of air diffusers from an ozone generator (Ozotech, Model 02-4PC10, Yreka, CA) was placed in the container 3. An air pump which was supplied along with the ozone generator, pumped air through the ozone generator at 2.6 Lpm. Ozone concentrations from the ozone generator with airflow rate of 2.6 Lpm was 1.8 mg/L under local atmospheric conditions. Ozone concentration in gaseous phase was found by using KI method. No off gas measurement was made, because all off gas was assumed used up. Six L of liquid fraction of manure with the characteristics shown in Table 3.1 was poured into all containers. Air was passed through the liquid fraction in container 1 and 2 at 2.2 and 3 Lpm, respectively. When air flow rates were chosen, care was taken to maintain adequate mixing of the liquid manure as mixing was important to maintain same dissolved oxygen level through out the liquid fraction of manure. Airflow rate was the average of many measurements by using soap film bubble column meter and an air flow rate measurement unit (Drycal, Bios International, Butler, NJ) taken at the start of the experiment. Lids covered container 1, 2 and 3 with an opening on the top of the containers. Container 3 was kept inside a larger plastic container, which was covered by a lid and connected to an exhaust fan. The

container had holes on its walls so that it could act as inlet for air. The exhausted air was directed out of the building so that there would be no ozone contamination inside the building. Manure was poured into a fourth container and left open without mechanical aeration. All the experiments were carried out at room temperature (10 – 15 ^{0}C). Total dissolved solids measurements in mg/L were obtained in every 24-h period for 18 days, using a conductivity meter (Model 50150, Loveland, CO). The conductivity meter was calibrated with buffer solutions for TDS, 500 mg/L and 9000 mg/L. Aeration at two levels, ozonation and natural settling treatments were repeated once and the measurements were recorded. After 18 days of aeration, the aerated liquid was filtered using a slow sand filter to remove the cell mass. The slow sand filter had a depth of 0.3 m and diameter of 0.05 m. Average size of the sand media used in the slow sand filter was 0.27 mm. The filtration speed in a slow sand filter is usually about 0.1 – 0.2 m/h (Logsdon 1991). Sand filter was washed with water before filtering the aerated liquid to remove impurities in the sand. After washing with water, sufficient time (12 h) was allowed for draining the media. Before collecting the filtered samples, about 1.5 L of aerated liquid was run through the slow sand filter and disposed. As limited amount of filtered samples were obtained from aeration level 1 (2.2 Lpm) and aeration level 2 (3 Lpm) treatments, the filtered liquid (1 L) from aeration level 1 was sent to a private laboratory (Envirotest, Edmonton, AB) for analysis of chemical parameters shown in Table 3.1. Filtered water from aeration level 2 was separated into two samples for biological analysis. Ozone was passed through one of the samples of 1 L for an hour at 1.8 mg/L by using the same ozone generator at the same airflow rate (2.6 Lpm) used to study the TDS removal. After ozone treatment a sample was sent to the laboratory

(Envirotest, Edmonton, AB) along with the slow-sand-filtered-liquid for biological analysis. The analysis for biological quality of slow sand filtered liquid was repeated once. The analysis for chemical and biological quality of the treated liquid was carried out according to the standard methods (Eaton et al. 1995). In biological analysis, amount of fecal coliform, total coliform and *e-coli* were found by using the most probable number (MPN) method.

Another study was made by using a domestic reverse osmosis (RO) package unit (Filmtec, Edina, MN) to remove TDS from the liquid fraction of manure. Thin film composite membrane (TFC) was used in this RO unit. The RO package unit can provide about 65 – 80 L treated drinking water at 415 kPa. This RO unit was connected to a pressure pump (Shurflo, Garden Groove, CA) as shown in Figure 4.1. This pressure pump is a diaphragm pump with a rated delivery of 6.4 Lpm at 415 kPa. The pump-pressure was adjusted by using a screw arrangement in the pump assembly. It is known that RO can remove more than 90 % of the TDS in the influent. However, quality of the influent and the operating pressure can affect the performance of the membrane (Belfort 1984). Therefore, liquid fraction of manure and tap water were passed through reverse osmosis unit at two pressure ranges (207 - 278 kPa and 345-414 kPa) and ten observations were made on permeate and concentrate volume at 5-min intervals to make a comparison between liquid fraction of manure and tap water at high and low pressure levels. This experiment had three replicates. An in house cartridge filter which was a part of the package unit was in place to protect the membrane from fouling (Figure 4.1). This cartridge filter could be replaced by an activated carbon or a sediment filter. An activated carbon cartridge filter was used to protect the membrane from chlorine when tap water

was used, since presence of chlorine in the tap water can affect the performance of membrane. Liquid fraction of the manure was passed through a slow sand filter before passing through the RO unit. As an additional protection, a 5-micron-sediment-cartridge filter which came as a package with the RO unit was also in place to protect the membrane. Samples of liquid fraction of manure and permeate collected at high pressure were analyzed at a private laboratory (Envirotest, Edmonton, AB) to compare the chemical parameters of permeate and drinking water standards (Table 3.1) for pigs. The analysis of the chemical parameters was carried out according to the standard methods (Eaton et al. 1995). Initial mean TDS values for the tap water and liquid fraction of swine manure were 200 and 4120 mg/L, respectively.

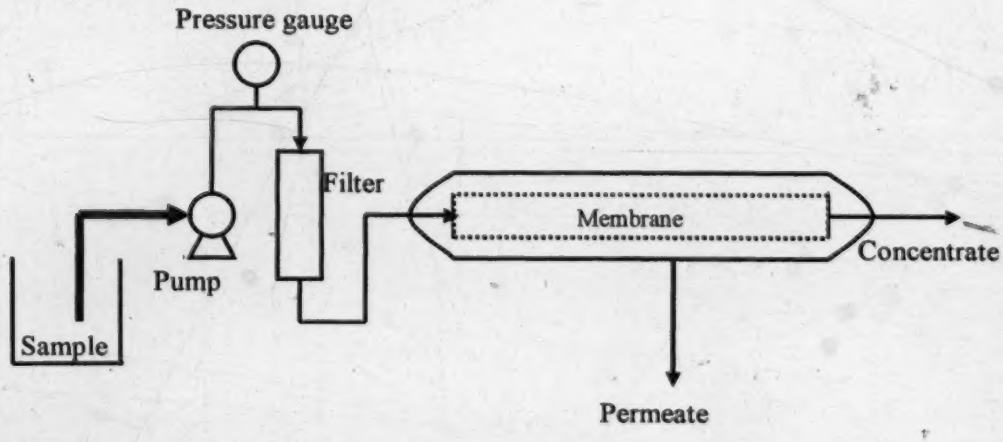

Figure 3.1 Schematic diagram of reverse osmosis system

Statistical Model for TDS removal by Aeration, Ozonation and Natural Settling

A Split plot design was used to analyze four treatments (Aeration level 1, Aeration Level 2, Ozonation and Natural Settling) in reducing TDS over a period of 18 days using SAS computer software. Split plot design is used in this study because it is

flexible and additional factors can be incorporated to increase the scope of the experiment if required. This experiment had two replicates.

$Y = \mu + T_i + I_j + B_k + TI_{ij} + TB_{ik} + \varepsilon_{ijk}$
Y- TDS mg/L,
μ - over all mean,
T - treatment,
I - intervals (time),
B- block, and
ε - natural error.

Statistical Model for TDS Removal by Reverse Osmosis

A Split-plot design was used to analyze two treatments (High Pressure and Low Pressure) for tap water and liquid swine manure using SAS computer software. Split plot design is used in this study because it is flexible and additional factors can be incorporated to increase the scope of the experiment if required. This experiment had 3 replicates.

Model Y_1 $Y_2 = \mu + P_i + S_j + T_k + PS_{ij} + PT_{ik} + ST_{jk} + PST_{ijk} + \varepsilon_{ijkl}$
Y_1- permeate volume, Y_2- concentrate volume
μ - mean
Pi – pressure (high, low)
S_j –source (manure, water)
T_k – time (intervals), and
ε_{ijkl} –error.

RESULTS AND DISCUSSION

Results (Aeration)

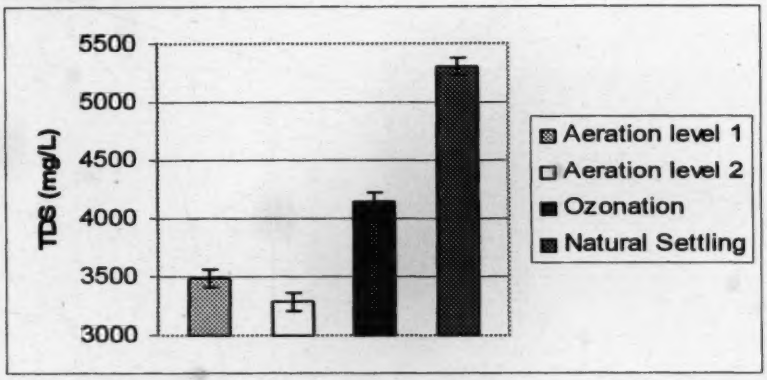

Figure 3.2 TDS levels after 18 days of treatment (Initial TDS - 6533 mg/L)

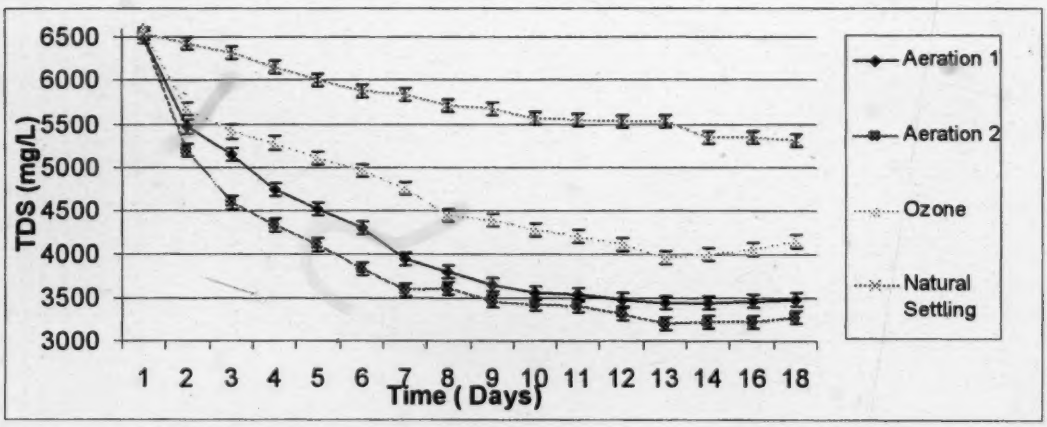

Figure 3.3 TDS levels over time for liquid manure treated by aeration and ozonation

Figure 3.4. Manure samples [(Left to right : Raw Manure, Aerated liquid level 1(18 d), Ozonated liquid(1d) and ozonated liquid(18 d)]

Figure 3.2 shows that the TDS levels after 18 days of aeration at level 1, Aeration at level 2, Ozonation and Natural Settling. Aeration at level 2 reduced TDS more than Aeration at level 1. Both levels of aeration reduced the TDS more than the ozone treatment. Ozonation reduced TDS better than natural settling. Figure 3.3 shows that the TDS reduction over 18 days for aeration at level 1, aeration at level 2, ozonation and natural settling. From Figure 3.3, it is evident that the TDS reduction rate decreased considerably over the time for aeration and ozonation treatments. Figure 3.4 shows the samples of raw, aerated and ozonated liquid. The ozonated sample became clearer than the aerated sample over an 18-d period. Eighteen days of aeration provided a liquid which had a dark-brown color (Figure 3.4).

Aeration level 1 (2.2 Lpm)

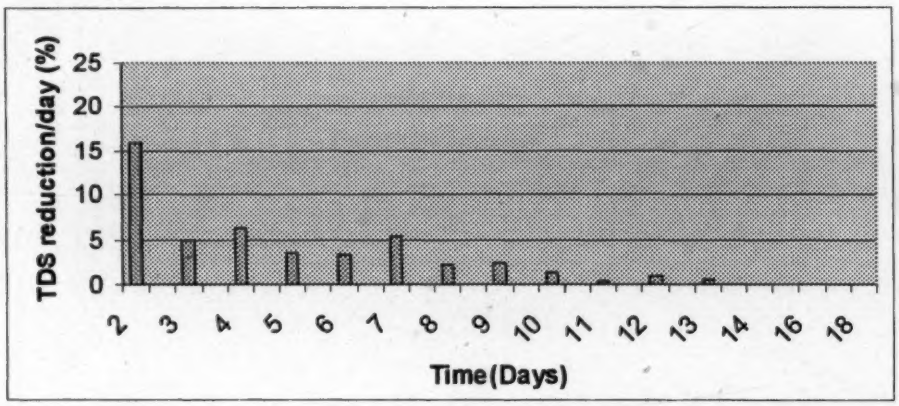

Figure 3.5 TDS reduction/day (% of total TDS reduction in 18 days) for aeration level 1

After the 9th day, TDS was not reduced significantly (P>0.05). The TDS reduction was apparent soon after the treatment was started. Especially on the very first day, TDS reduced to 1035 mg/l, which is 16 % of the initial TDS (Figure 3.5). After the 1st day, TDS reduction was less than 6 % of the initial value (6500 mg/l).

Aeration level 2 (3 Lpm)

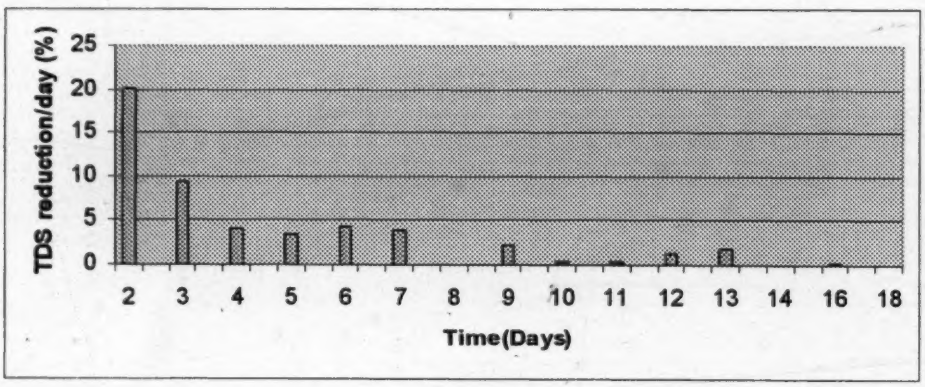

Figure 3.6 TDS reduction/day (% of total TDS reduction in 18 days) for aeration level 2

Until the 12th day TDS reduced significantly ($P<0.05$). In this experiment TDS reduction was 20 % of the initial TDS on the 1st day (Figure3.4). On the 2 nd day, TDS reduction was 9 %. As the number of days increased, TDS reduction became less (Figure 3.3). After the 7 th day, the TDS reduction was 2 % or less than 2 %.

Discussion (Aeration)

Biochemical reaction during aerobic treatment is shown in Equation (3.1)

$$\text{Organic matter} + O_2 \longrightarrow \text{Biomass} + CO_2 + H_2O + NH_4^+ + NO_3^- + NO_2^- + SO_4^- \text{----(3.1)}$$

As shown in Eqn (3.1), the aerobic microorganisms biodegrade organic substance into cell mass, when air is supplied. This process produces carbon dioxide, water, ammonium, nitrates, nitrites and sulfates. Microorganisms are active in the liquid manure. Therefore, when air was supplied the biodegradation process started immediately. As microorganisms converted organic substrate into cell mass, TDS became reduced. The TDS reduction on the first day for aeration levels 1 and 2 was rapid as shown in Figures 3.5 and 3.6, respectively. Readily available substrate in the liquid manure was rapidly converted to cell mass on the first day. As the time progressed, the availability of the substrate was limited. Therefore, TDS reduction became slower. However, Figures 3.5 and 3.6 shows that a decrease in TDS reduction did not follow a regular pattern, since TDS reduction depends on the microbial growth and biodegradability of substrate. During the last nine days TDS reduction was very little when compared with the first nine days (Figures 3.5 and 3.6). Limitation of nutrients such as nitrogen and phosphorous could also slowdown the biodegradation of the substrate. New cell synthesis requires nitrogen and phosphorus. Chemical analysis

showed that the concentration of organic nitrogen total kjeldahl nitrogen (TKN) after aerating for 18 days was 110 ppm. Therefore, nutrients were available for microorganisms for their cell synthesis. After 14 days aeration, levels 1 and 2 showed an increase in TDS. It is common in many biochemical operations for microorganisms to be without exogenous substrate for extended periods of time (Cheremisinoff, 1985). Under such conditions, a portion of the cell mass may be used to supply maintenance energy, which is known as endogenous metabolism. These results in loss of cell mass or microbial decay. Microbial decay is due to more than just endogenous metabolism. Another factor resulting in microbial decay is cell lysis. As some organisms die, they begin to leak their internal content into media. Therefore, each time cell lysis and endogenous metabolism happens there will be a decrease in the cell mass and suspended matter or settled matter. This would result not only in slowing down TDS reduction but also sometimes in increasing it.

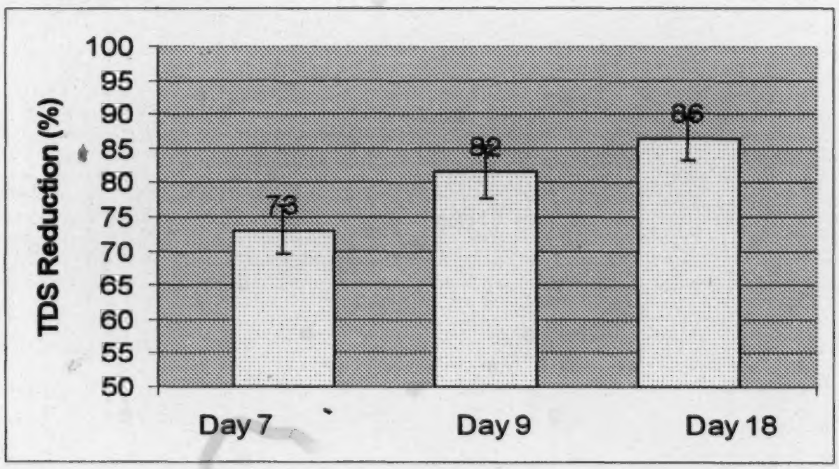

Figure 3.7 TDS reduction achieved on day 7, 9 and 18 for aeration level 1

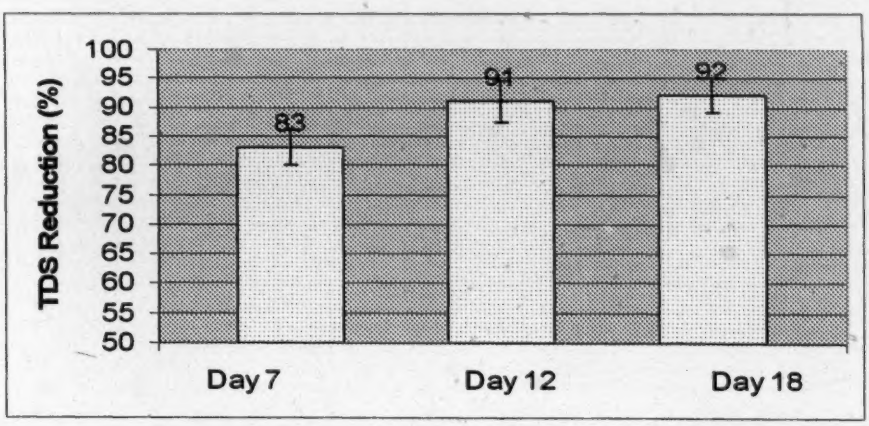

Figure 3.8 TDS reduction achieved on day 7, 12 and 18 days for aeration level 2

Statistical analysis shows that until the 16th day, TDS of the two treatments were (Figure 4.2) significantly different ($P<0.05$). TDS reduction was faster in aeration level 2. Faster TDS levels reduction at higher aeration level was explained as follows; Transfer of oxygen from gas to the liquid phase is a function of over all oxygen transfer coefficient K_La and oxygen deficiency (Bayramoglu et al. 2000).

$$OTE = K_La\ (C^*-C) \qquad (3.2)$$

Where:
OTE- oxygen transfer efficiency,
K_La – overall oxygen transfer coefficient (h^{-1}),
C* - mean saturated dissolved oxygen (mg/L) , and
C- mean dissolved oxygen needed by the organic matter (mg/L).

Equation 3.3 is a scale up model for fine pore aeration using oxygen transfer coefficient (K_La) as a scale up parameter (Boyle 1986).This model was derived by using dimensional analysis as a start point. At higher aeration rate, overall oxygen transfer coefficient is also higher (Equation 3.3). Therefore, the oxygen transfer efficiency (OTE) is also higher (Equation 3.2) and higher oxygen transfer efficiency results in faster TDS reduction.

$$K_La/Q_a = [\rho\, Q_a (Ndo)^2/\mu]^{0.046}\, [\, Q_a^{\,2}\, (Nd_o)/g]^{-0.126} [\, d_d/T_d]^{0.69} [T_w/T_d]^{-0.446} \qquad (3.3)$$

Where:
Q_a - airflow rate /unit volume,
ρ - density,
μ - viscosity,
N -number of bubbles,
do- diffuser orifice diameter,
g - gravitational constant,
d_d- diffuser depth,
T_d-liquid depth, and
T_w- tank width.

However, TDS reduction rate decreased, after 7 days of aeration at level 2 due to the limitation of readily available substrate. Aeration up to 18 days achieved only 86% and 92% of TDS reduction for aeration at levels 1 and 2, respectively (Figure 3.7 and 3.8). Eighteen days of aeration appears to be expensive in terms of power consumption. As 7 days of aeration at level 2 achieved 83% of the TDS reduction, it was suggested that blending of fresh water after 7 days of aeration at level 2 to reduce the TDS levels would be more economical. It should also be noted that after aerating for 7 days at aeration level 2, suspended cell mass should be removed and the liquid be disinfected before animal consumption.

Ozonation

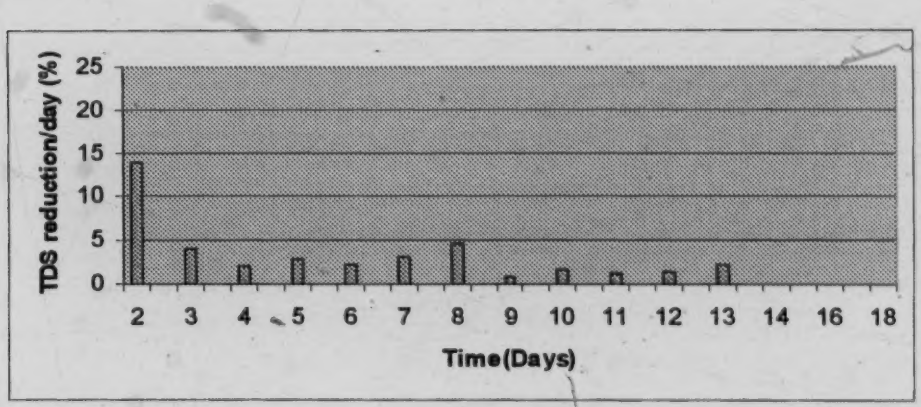

Figure 3.9 TDS reduction/day (% of total TDS reduction in 18 days) for ozonation

Aeration and ozone treatments were significantly different ($P<0.05$). Figures 3.2 and 3.3 show that aeration achieved faster and more TDS reduction than ozonation, eventhough ozonation produced clearer water (Figure 3.4). Oxidation rates of organic materials were rapid during the early stages of ozonation and then the rate slowed considerably (Figures 3.3, 3.9). This was probably due to: 1) concentration of readily oxidizable organic material becoming lower, and 2) organic oxidation products become more refractory to ozone. Some organic materials like oxalic, formic and terepthallic acids and phenolic compounds need a lengthy time to oxidize and produce CO_2 (Rice 1981). Wang and Pai (2000) reported that ozonation increased the dissolved organic carbon from the suspended or settled sludge. Deleris (2000) also reported that high doses of ozone solubilized and mineralized sludge and increased the dissolved organic carbon. Therefore, TDS reduction by ozone treatment was not as effective as aeration treatments.

Further, ozone treatment could leave unknown intermediate products in the liquid. The effects of such intermediate products are yet to be investigated. However, ozone treatment removed the organic color from the liquid manure by oxidizing the organic compounds responsible for that particular color. Lotan (2000) also claimed that ozone treatment reduced the organic color in the ground water.

Natural Settling

Aeration and ozonation reduced the TDS faster than natural settling ($P<0.05$) (Figure 4.2). Natural settling also reduced the TDS, but the reduction rate was slower than mechanical aeration. In natural settling, the biodegradation depends on the ability of oxygen to diffuse from the surface. As the depth increases, anaerobic condition exists (Overcash et al. 1983). Natural aeration lagoons alone are not commonly recommended because of their size and performance which indicates that the natural aeration lagoons do not provide a dischargeable effluent and odour control (Overcash et al. 1983). Mechanically aerated lagoons can provide positive odour control when properly designed and managed (Fleming 1986).

Table 3.1 Chemical parameters of raw liquid manure and aerated liquid manure

Parameter	Liquid Manure	Aerated liquid manure (Aeration level 1)	Standards	Detection Limits
pH	7.6	**8.7**	6.5 to 8.5	0.1
TDS (mg/l)	**6500**	**3475**	3000	1%
Alkalinity (mg/l)	**5130**	1140	5000	5
Hardness (mg/l)	413	79	N/A	
Calcium (mg/l)	129	25.9	1000	0.5
Sodium (mg/l)	317	362	500	1
Sulfate (mg/l)	**1150**	**791**	750	0.5
Nitrite-Nitrate N (mg/l)	1.5	1.8	100	0.1
Iron (mg/l)	**4.41**	**2.42**	0.3	0.005
Aluminum (mg/l)	1.13	0.4	5.0	0.01
Arsenic (mg/l)	0.0310	0.0326	0.5	0.0004
Berylium (mg/l)	<0.0002	<0.0002	0.1	0.002
Boron (mg/l)	1.19	1.23	5.0	0.05
Cadmium (mg/l)	0.001	0.002	0.02	0.001
Lead (mg/l)		0.006	0.1	0.005
Nickel (mg/l)	0.082	0.13	1.0	0.002
Zinc (mg/l)	2.57	0.861	50	0.001
Total Suspended Solids	5100	82		3

Table 3.1 shows that the comparison of chemical parameters of liquid manure, aerated liquid manure and the standards. The drinking water parameters were compiled from available standards (CWQG 1995; Coote and Gregorich 2000; PPRG 2000). After aerating the liquid manure for 18 d, the liquid manure was passed through a slow sand filter to remove the suspended matter. After 18 d of aeration, pH had increased (Table 3.1), and the pH level was just above the suitable level recommended for drinking for pigs. Alkalinity in the liquid manure was high which was reduced after aeration and filtration. Alkalinity is a measure of acid neutralizing capacity and how much acid can be added to a liquid without causing significant change in pH. Alkalinity is contributed to by carbonates and bicarbonates. The following chemical equilibrium shows the relationship among the bicarbonates, carbonic acid and CO_2.

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^- \qquad (3.4)$$

Carbonic acid and carbonates are in the equilibrium. When air is bubbled through the liquid manure, air would strip out the dissolved CO_2. As the dissolved CO_2 is removed, bicarbonates will be converted to carbonic acid to maintain the equilibrium. This will result in the reduction of alkalinity. During aeration, volatile organic matter are stripped out and lost to the atmosphere. The stripping of volatile fatty acids can increase the pH. In water treatment, aeration method is used to increase the pH level in the water. Further, Chao and Westoholf (2002) found that addition of pressurized air decreased the pH of water above 8.5 from 7.0. This is due to the removal of dissolved carbon dioxide. Lytle et al. (1998) also found that the aeration increased the pH of water and derived Equation (3.4) to find the approximate final pH after aeration by using equilibrium based

relationships. Eqn 3.4 shows that the final pH increases if the dissolved carbon dioxide is removed from the liquid.

$$pH_f = pH_i - \log [CO_2]_f/[CO_2]_I \quad (3.5)$$

where:

pH_f - final pH after aeration,
pH_i - initial pH,
$[CO_2]_f$ - final CO_2 concentration, and
$[CO_2]_I$ - initial CO_2 concentration.

Further Lamotta (1995) also found that the pH increased as the number of trays is increased to remove dissolved CO_2 using tray aerators.

Further experiments by Chao and Westoholf (2002) showed that aeration removed 65 % of calcium. Dissolved calcium becomes insoluble as aeration increases the pH level and settles as calcium carbonate. As calcium carbonates are formed, alkalinity level reduces further. Table 3.1 shows that the hardness and calcium level after aeration and filtration were reduced.

Aeration can reduce dissolved iron content. The ferrous form of the dissolved iron would be converted to the ferric form which is insoluble and can be removed by filtration. Table 4.1 shows that the iron content in the liquid manure was reduced after aeration. However, presence of iron does not cause any harmful effect for pigs.

Chemical analysis for the heavy metals showed that the concentrations of heavy metals were within the recommended levels (Table 3.1). Eventhough some of the sulfate was removed in the process of aeration and filtration, sulfate levels after treatment exceeded the drinking water standard. In the biodegradation process, sulfate is a by-product as shown in equation 3.1 and remains in the aerated liquid manure. By diluting the treated liquid manure with water, the sulfate level could be reduced to meet the

standards. This dilution can also reduce the marginally exceeding high pH to fall within the recommended standards.

Table 3.2 Aerated liquid TDS after 7 days for aeration level 2 (mg/L)

Parameter	Liquid manure	Aerated liquid	Fresh water	After blending with 20% fresh water
TDS(mg/l)	6500	3590	210	2914

As discussed before, aeration level 2 was effective for first 7 days in reducing TDS. TDS level after 7 days was 3590 ppm, which was higher than the drinking water standard. This level could be reduced by blending 20 % fresh water, which is low in TDS. However, the aerated liquid had to be passed through a slow sand filter to remove suspended solids and pathogens before blending with fresh water. The August 2002, monthly mean value of TDS for city of Edmonton water supply was 209 ppm (www.edpower...). Addition of 20 % fresh water with the aerated liquid would have brought down the TDS to 2914 ppm to meet the drinking water limits for pigs. Apart from TDS, Table 3.1 shows that alkalinity, sulfate and iron content in the fresh liquid manure were higher than the required level. Presence of iron was not mentioned in the PPRG (2000) as harmful to the pigs. Alkalinity level was expected to reduce during aeration as discussed above. Presence of sulfate higher than 750 ppm could cause osmotic diarrhea in weanling pigs (PPRG 2000). However, PPRG (2000) claimed that higher sulfate levels as high as 2000 ppm did not result in reduced growth even though the osmotic diarrhea was profuse. The aerated water possessed organic color indicating that some organic compound, which were not easily biodegradable, were left in the treated

water. The presence of residual organic content would be lower in the blended liquid as significant amount of TDS was made up of inorganic matter (Table 3.1). As manure has been deliberately incorporated into animal diets for their nutrient properties for almost 40 years and the aerated liquid had a bearable earthy smell, the treated liquid after blending with fresh water could be used for drinking purposes for pigs.

Heavy foam formation

Aeration and ozonation treatments produced foam formation in the liquid fraction of the swine manure. Ozonation produced heavier foam formation than aeration. Being a powerful oxidant, the passing of ozone produced rapid oxidation reaction which would have resulted in heavy foam formation. However, foam formation reduced with the time. The intense aeration and agitation conditions in liquid manure also produced heavy foam which was chocolate in color and similar to that reported in activated sludge plants (Winkler 1981). According to Winkler (1981), the foam formation in the activated sludge plant is due to the growth of filamentous microorganisms, which have the effect of stabilizing the foam by effectively trapping the air bubbles. In this experiment foam formation reduced greatly after aerating for a week. After 18 days of aeration, very little foam formation was observed. This might be due to the unavailability of easily degradable substrate as the time progressed. It was also noted that the ozone treatment (1 h) for disinfection after aerating at level 2 for 18 days did not produce heavy foam formation. Therefore, the foam formation may be related to the availability of biodegradable and chemically oxidizable organic matter in the liquid fraction of the manure.

Scaling up

The aeration experiment shows that aeration at the rate of 3 Lpm resulted in 83% of the required TDS reduction during the first 7 days. Therefore, 7 d of aeration appears to be an appropriate period of time. This bench scale experiment was scaled up to find the suitability for a large scale application. Equation 3.6 (Boyle 1986) is a scale up model based on the overall oxygen transfer coefficient (K_La), which is a parameter controlled by the process (Boyle 1986). Equation 3.6 is derived using dimensional analysis as a starting point. K_La is a function of airflow rate, volume, density, and viscosity, number of bubbles, orifice diameter, diffuser depth, aeration tank depth, and aeration tank width (Boyle 1986). Boyle (1986) claimed that this scale up model (Equation 3.6), showed error of 10 %, when tested.

$$K_La/Q_a = [\rho\, Q_a\, (Ndo)^2/\mu]^{0.046}\, [\, Q_a^{\,2}\, (Nd_o)/g]^{-0.\,126}[\, d_d/T_d]^{0.69}[T_w/T_d]^{-0.446} \qquad 3.6$$

Where:

Q_a - airflow rate /unit volume,
ρ – density ,
μ – viscosity ,
N -number of bubbles,
do- diffuser orifice diameter,
g - gravitational constant,
d_d- diffuser depth,
T_d-liquid depth, and
T_w- tank width.

Bench scale

$$K_La_1 = [\rho\, Q_{a1}\, (Ndo)^2/\mu]^{0.046}\, [\, Q_{a1}^{\,2}\, (Nd_o)/g]^{-0.\,126}[\, d_{d1}/T_{d1}]^{0.69}[T_{w1}/T_{d1}]^{-0.446}\, Q_{a1} \qquad 3.7$$

Large Scale

$$K_La_2 = [\rho\, Q_{a2}\,(Ndo)^2/\mu]^{0.046}\,[\,Q_{a2}^{\,2}\,(Nd_o)/g]^{-0.126}[\,d_{d2}/T_{d2}]^{0.69}[T_{w2}/T_{d2}]^{-0.446}\,Q_{a2} \qquad 3.8$$

If liquid fraction of swine manure with same characteristics and a similar ceramic diffuser were assumed to be used in the large scale unit as in the bench scale unit, density, viscosity, and orifice diameter were the same for both units. Equations 3.7 and 3.8 can be combined to equation 3.8

$$\frac{K_La_1}{K_La_2} = \frac{Q_{a1}^{0.794}\,N_1^{-0.034}\,[\,d_{d1}/T_{d1}]^{0.69}[T_{w1}/T_{d1}]^{-0.446}}{Q_{a2}^{0.794}\,N_2^{-0.034}[\,d_{d2}/T_{d2}]^{0.69}[T_{w2}/T_{d2}]^{-0.446}} \qquad 3.9$$

Liquid depth (T_{d1}) and area of the bench scale experiment were 0.012 m and 0.0588 m^2, respectively. The area of the bench scale unit was assumed to be a square. Eqn. 3.9 shows that the ratio of the overall oxygen transfer coefficient of bench scale and large scale experiment depends on the air flow rate (Q_a), liquid depth (T_d), diffuser depth (d_d), tank width (T_w) and number of bubbles produced (N).

The airflow rate, liquid depth, diffuser depth and cell width of the bench scale experiment were known. Airflow rate/unit volume (Q_{a1}) = 0.5 m^3/min, number of bubbles (N_1)= unknown, diffuser depth (d_{d1}) = 0.012 m, liquid depth (T_{d1}) = 0.012 m, and tank width (T_{w1}) = 0.237 m

A diffuser depth and liquid depth of 3 m and 3.5 m was assumed for the large scale aeration unit. The liquid depth of the aeration tank is usually from 1.8 - 4.6 m

(Eckenfelder 2000). The airflow rate, number of bubbles, liquid depth, and diffuser depth and tank width of the large scale experiment is as follows:

Airflow rate /unit volume (Q_{a1}) = 0.1168 m^3/min, number of bubbles (N_1)= the same as the bench scale unit, diffuser depth (d_{d2}) = 3 m, liquid depth (T_{d2}) = 3.5 m, and tank width (T_{w2}) = 2 m

Assuming that the number of bubbles released by the air diffuser for bench scale unit and large-scale unit was the same, the ratio of the oxygen transfer coefficients (K_La_1/ K_La_2) was found by using eqn.3.9.

$K_La_1/ K_La_2 = 0.77$

The ratio of the oxygen transfer coefficients showed that the oxygen transfer coefficient for bench scale experiment was 0.77 times the large scale unit. Same oxygen transfer coefficient in large scale and bench scale unit means the same TDS reduction rate in both the units. However, it has to be noted that this scale up model has an error of 10 % (Boyle 1986) and David et al.(1994) claimed that about 7 % variation in oxygen transfer efficiency was observed between the finest and porous ceramic diffusers used in his research. Therefore, a value of 0.77 for the ratio of oxygen transfer coefficients of bench scale and large scale unit was considered to be suitable for a conservative design. Large scale dimensions were worked out based on the following available details found in a literature (David et al. 1994) about a study conducted at the Monroe wastewater treatment plant using ceramic diffusers. A quotation was obtained for a suitable fan to deliver the required air flow rate (Cincinnati fan selectors, Mason, OH). The diffusers and fan specifications are given below along with the estimated cost for electricity.

Type of diffuser- Ceramic Disc type

Diameter of the diffuser- 0.019 m

Length of the diffuser-0.225 m

Flow rate of the diffuser- 3.4 m^3/h

Pressure drop across the diffuser- 7.5 cm of water

Volume of the tank- 14 m^3

Assumed diffuser depth- 3.5 m

Assumed evaporation loss- 40 % of the total volume

Number of air diffusers required – 29

Manufacturer- Cincinnati fan selectors, Mason, OH

Model of the fan- SPB 9

Air flow rate- 1.636 m^3/min

Power consumption- 0.375 kw

Static pressure- 15 cm of water

Cost of electricity- 0.067 cts/kwh (http://www.epcor-)

Water consumption per growing pig in 100 days- 400 L

Estimated energy cost per growing pig- $ 0.20

Pathogen Removal

As per the fresh manure productions and characteristics given in ASAE (1997), total and fecal coliform bacteria counts are as follows.

Table 3.3 Pathogens count in fresh manure (ASAE 1997)

Total coliform(MPN/100 ml)	52×10^6
Fecal coliform(MPN/100 ml)	21×10^6

Table 3.4 Pathogens count in liquid manure sample collected from Swine Research Center

Total coliform (MPN/100 ml)	> 15000
Fecal coliform (MPN/100 ml)	> 15000
Escheria.coli (MPN/100 ml)	> 15000

Table 3.5 Pathogens count in the aerated liquid after passing through a slow sand filter

PATHOGENS	**COUNTS (MPN)**	**NO.OF SAMPLES**
Total coliform (MPN/100 ml)	12	2
Fecal coliform (MPN/100 ml)	12	2
Escheria.coli (MPN/100 ml)	12	2

After aeration and slow sand filtration, the presence of fecal coliform, total coliform and *Escherichia coli* were reduced (Table 3.5). However, only two samples were obtained and analyzed for pathogens. PPRG (2000) recommends that the drinking water for pigs should not contain a coliform counts more than 5000/100-ml as a

guideline. Aeration can reduce pathogens. Burton (1992) claimed that aeration could be used to reduce pathogens in pig slurry. Bicudo and Syoboda (1995) reported that eventhough the intermittent aeration reduced the bacterial concentration, the fecal coliform and *streptococci* bacteria were found in the order of 10^6. Munch et al.(1987) reported that the presence of *E-coli* and *streptococci* in aerated slurry was less than in non aerated slurry. Literature further showed that slow sand filtration also removed pathogens. Slow sand filtration removed at least 90 % *E-coli* effectively (Linda 1983; Fogel et.al 1993; Timms et al, 1995. Linda (1983) also found out that the graded sand and not graded sand did not make any significant difference with regard to removing the pathogens. Therefore, most of the pathogen reduction shown in the Table 3.5 would have been taken place during the slow sand filtration. In addition to pathogen removal, the formation of an organic layer on the top of the sand bed could act as a bio-filter, which could enhance the quality of the filtered liquid. However, the possibility of pathogen out-break was a matter of concern. The period of usage without outbreak was not determined in this project. Therefore, further disinfection by using ozone was recommended.

Table 3.6 Pathogen count in liquid manure after aeration, slow sand filtration and ozonation for one sample

Total coliform (MPN/100 ml)	9
Fecal coliform (MPN/100 ml)	4
Escheria.coli (MPN/100 ml)	4
Salmonella (MPN/100 ml)	Not identified

Table 3.6 shows the pathogen counts after aeration slow sand filtration and ozonation for an hour. In this experiment ozone was passed through liquid manure for an hour after aeration and slow sand filtration. From Table 3.6 it was evident that the ozone treatment reduced the pathogen further more than slow sand filtration. The effect of killing microorganisms by ozone could be reduced when oxidizable organic matter is present in the liquid. However, after aeration and slow sand filtration, the presence of readily oxidizable organic matter was reduced eventhough it was not completely removed in this experiment. For practical application in this situation effectiveness and duration of ozonation needs to be further studied. In addition to pathogen removal, the ozonated liquid did not bear a bad smell. Wu and Park (1999) reported that the malodorous bacterial metabolites (phenol, p-cresol, p-ethyl-phenol etc.) were found eliminated after ozone treatment and the odour intensity were reduced. This ozonated slurry did not regain its original offensive odour intensity after a month of storage subsequent to the ozone treatment (Wu 1999).

Reverse Osmosis

Table 3.7 Chemical parameters before and after RO filtration at high pressure

Parameter	Liquid manure	Std. dev	After RO treatment	Std. dev	Drinking Water Standards *
PH	7.25	0.2	7.5	0	6.5 to 8.5
Alkalinity (mg/L)	3110	99	565	41	5000
TDS (mg/L)	**4095**	7.07	800	101	3000
Hardness (mg/L)	348	42	19	10	N/A
Calcium (mg/L)	113	3	6	3	1000
Magnesium (mg/L)	21	16	1	0.5	N/A
Sodium (mg/L)	160	25	32	2.8	500
Sulfate (mg/L)	**788**	356	6	1	750
Nitrite-Nitrate N (mg/L)	<0.1	0	<0.1	0	100

* CWQG 1995; Coote and Gregorich 2000; PPRG 2000

The permeate water was as clear as tap water (Figure 3.11) and did not posses any offensive odour. Chemical parameters of the liquid manure are shown in Table 3.7 show that the TDS and sulfate level were higher than the drinking water standards. The RO filtered water met the drinking water standards for chemical parameter as shown in the Table 3.7. The drinking water parameters were compiled from available standards (CWQG 1995; Coote et al. 2000; PPRG 2000). Liquid manure usually contains a high level of dissolved organic matter. Dissolved organic matter gave a dark organic color to the liquid manure (Figure 3.11).

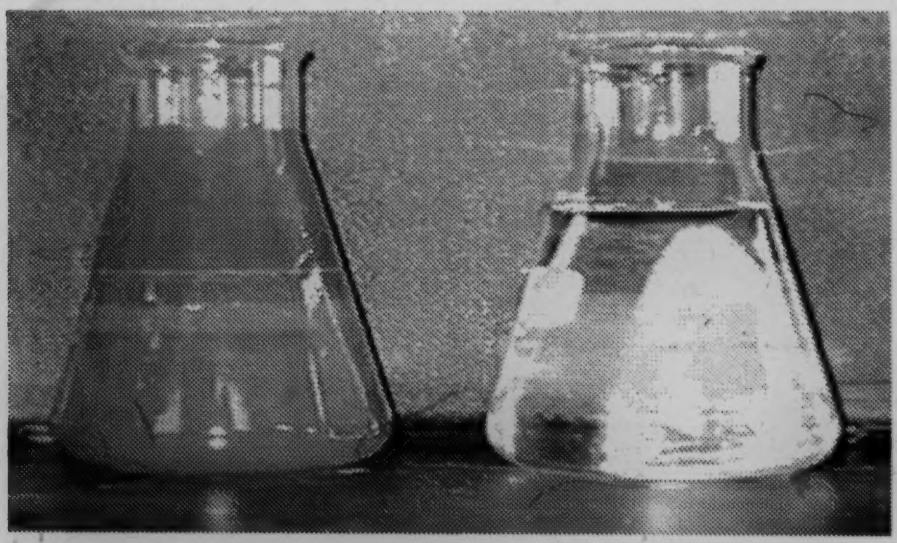

Figure 3.10 Liquid manure before (Left) and after RO filtration (Right)

Table 3.7 shows that about 80 % TDS rejection was achieved in the treated water at a high pressure. Organic matter in the liquid manure would have been mainly undigested food and had a higher molecular weight. Therefore the RO membrane was very effective in organic removal as the treated water was very clear as shown in the Figure 3.10. However, RO membrane could get fouled quickly. The presence of high organic matter along with high hardness had potential to foul the membrane. When liquid manure was passed through RO membrane more than two hours, treated water flow rate became so low that it was negligible. Calcium and magnesium salts could also form hard scale on the membrane surface on the long run which is usually very hard to remove (Belfort 1984). Therefore, pretreatment was required before RO filtration in order to remove hardness and organic matter.

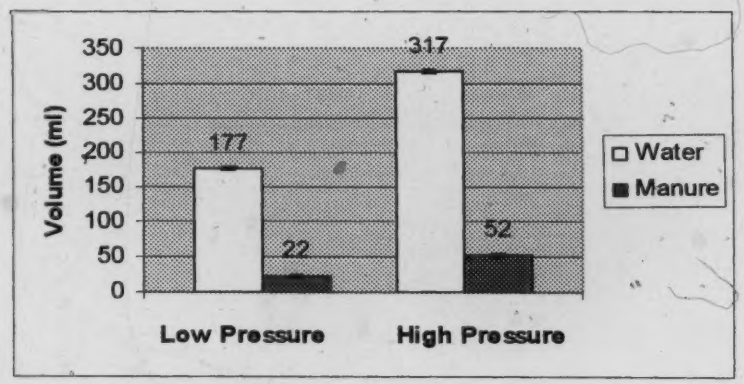

Figure 3.11 Treated liquid volume

Treated liquid volume under low pressure and high pressure were ($p<0.05$) different for both water and manure. These differences were due to the differences in solute concentration and applied pressure for water and manure, which can be theoretically explained as follows. The osmotic pressure π, is given by van't Hoff formula (Belfort 1984) for dilute solutions,

$$\pi = cRT \qquad (3.10)$$

where c is the molar solute concentration, R is the universal gas constant, and T is the absolute temperature. This formula is the same as the pressure formula of an ideal gas. For concentrated solutions (High TDS), osmotic pressure coefficient, (K_o) is introduced (Belfort 1984).

$$\pi = K_o cRT \qquad (3.11)$$

Equation (3.11) indicates that the osmotic pressure depends on the solute concentration. Solute is the substance dissolved or in the solution. As the osmotic pressure becomes higher, the pressure needed to overcome the osmotic pressure also becomes higher. After removing suspended solids by filtering, TDS measurement indicated the solute concentration in the water and manure. Since the solute concentration in manure was

greater than water, the volume of effluent produced was lower when pretreated liquid manure was used as influent. Further the volume of treated water depended on the difference between applied pressure and osmotic pressure (McCabe et al. 2001). Therefore, as the applied pressure was increased, the effluent volume was increased as shown in Figure 3.11. To increase the flow rate, a nano-filter could also be used in the place of RO, which could remove the compounds with molecular weight higher than 300. However, the literature showed that nano-filtration membranes were more prone to organic fouling than TFC membranes (Ozaki 2000).

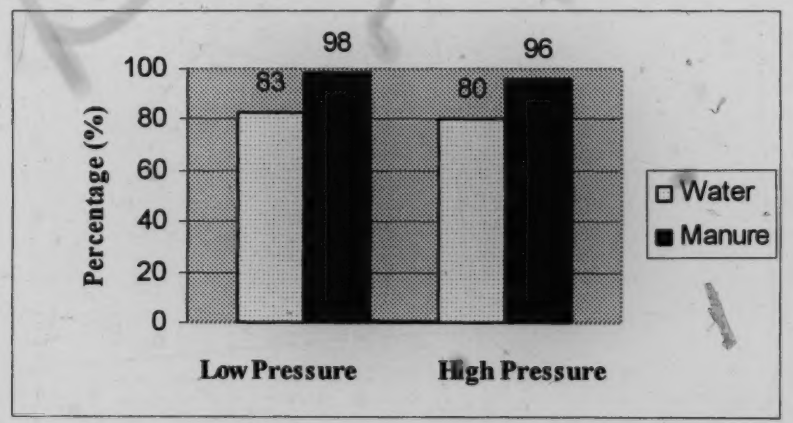

Figure 3.12 Rejection of liquid manure and tap water at low and high pressure

As shown in Figure 3.12, the RO unit rejected 96 % and 80 % of the liquid manure and tap water, respectively at the high pressure which was recommended by the suppliers of the RO unit. The treated liquid volume (Permeate volume) by RO was very low. Lahlou (2000) claimed that 50-75 % of the influent appears as concentrate in most of the treatment systems when RO technology is used. Figure 3.12 shows that 80 % of the tap water appeared as concentrate at high pressure, eventhough the influent tap water had

a mean TDS of 200 mg/L. The volume of rejection depended on the solute concentration and applied pressure.

CONCLUDING REMARKS

Aeration at level 2 (3 Lpm) resulted in faster TDS reduction than aeration level 1 (2.2 Lpm), as higher aeration increased oxygen transfer efficiency. Ozone treatment resulted in less TDS reduction compared to aeration. Aeration at level 2 was effective during the first 7 days as after 7 days, the rate of TDS reduction became very low due to low availability of biodegradable substrate. Therefore, 7 days of aeration appears to be an appropriate time in reducing the TDS in the liquid fraction of manure. Further, it has been suggested that blending of aerated liquid after 7 days (Aeration level 2) with the fresh water would reduce the TDS to meet the drinking water standards. This blended liquid could be used as drinking water for pigs. However, pig response and performance need to be studied. Aeration at level 1 increased the pH probably due to the stripping of the volatile fatty acids and CO_2 while reducing the alkalinity and hardness levels over a period of 18 days. Slow sand filtration removed pathogens sufficiently in the aerated liquid and met the drinking water guidelines for pathogens. Ozone treatment for an hour further lowered the pathogen count. The bench scale experiment was scaled up to treat 14 m^3 of liquid fraction of swine manure using overall oxygen transfer coefficient as scaling factor. The estimated cost for electricity was $ 0.20/growing pig

When liquid manure was treated by a RØ system, clear water was produced. The chemical analysis showed that the treated water quality met with the chemical drinking water chemical standards. At high pressure, a greater volume of water was produced. As TDS increased, the volume of the water filtered became lower. The volume of treated

water produced by the RO treatment at high pressure was as low as 4 %. The remaining liquid manure would go as waste and waste disposal could become a problem. Judging from the liquid manure quality, pretreatment is needed to prevent membrane from fouling quickly. Pretreatment would make this RO process more expensive. Eventhough RO produced very clear water, it does not appear to offer a viable solution with regard to recycling liquid manure as drinking water for pigs as the permeate volume is a meager 4% of the influent volume.

Area for further Research

1) Pig response and performance to the treated liquid

Poor water quality would affect the pig feed intake and performance. Therefore, studying the response and performance may provide information needed for convincing the pork producers to use recycle drinking water for pigs

2) Performance and economics of a large scale experiment

Mechanical aeration in waste water treatment can be very energy intensive. The energy-cost estimated for providing drinking water for a facility with 300 growing pigs was $0.20 per growing pig. As aeration is a widespread waste management practice in various industries and provide some odour control, studying the performance of this large scale unit which could treat liquid fraction of manure, would provide more useful information

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CHAPTER 4 CONCLUSIONS AND RECOMMENDATIONS

Pork production has become a flourishing industry in Canada while water supplies are becoming a scarce commodity. The large quantities of water required for the pork producers are a concern to the industry. Normally more than 90 % of the livestock manure contains water. Considering the high requirement for water in a pig operation, there may be an opportunity to treat the liquid fraction of the manure for drinking purposes. A series of experiments were conducted to separate liquid fraction of swine manure and remove total dissolved solids with the objective of recycling the liquid fraction as drinking water for pigs. The experiments and their results were discussed in the previous chapters. In the following section, summary of the findings and recommendations are given.

THE FOLLOWING CONCLUSIONS WERE DRAWN FROM THIS STUDY

1) Since alum, lime and gypsum addition did not produce satisfactory results with regard to settling, natural settling was considered as a suitable method to separate the liquid fraction from swine manure.

2) Aeration level 2 (3 Lpm) was very effective during the first 7 d in reducing the TDS level in the liquid manure. After 7 d, reduction of TDS became very low due to less availability of biodegradable substrate. Blending of 20 % fresh water with the filtered liquid after 7 d of aeration at aeration level 2, provides a liquid with TDS less than 3000 ppm. The cost estimated for power consumption in aerating 14 m^3 of liquid fraction of swine manure is $ 0.201 per growing pig.

3) Slow sand filtration removed pathogens, effectively in the treated liquid fraction and met the drinking water guidelines for pathogens. Ozone treatment (1.8 mg/L) also reduced the pathogen counts.

4) The water treated by an RO system was as clear as tap water and the chemical analysis showed that the quality of the treated water met the chemical parameters for drinking water for pigs. The volume of treated water produced by RO treatment was as low as 4% at 345-414 kPa.

RECOMMENDED TREATMENT SCHEME FOR RECYCLING LIQUID FRACTION OF MANURE AS DRINKING WATER FOR PIGS

Natural settling was chosen as the economical and relatively simple method that can be used in separating the liquid fraction from the solid fraction of swine manure in this treatment scheme. After natural settling, aeration was used to degrade and reduce the total dissolved solids (TDS) in the liquid fraction of swine manure. Fine pore aeration technique appeared to be feasible relative to chemical treatment, reverse osmosis and ozonation in this study. After aeration, the liquid was passed through a slow sand filter to remove suspended particles and pathogens. An additional treatment of at least an hour of ozonation depending on the effectiveness of ozone in the treated liquid was recommended to ensure that harmful pathogens were reduced to acceptable levels. Both the chemical and biological parameters obtained for this project showed that the treated liquid after blending with 20 % fresh water would be suitable to be used for pig consumption.

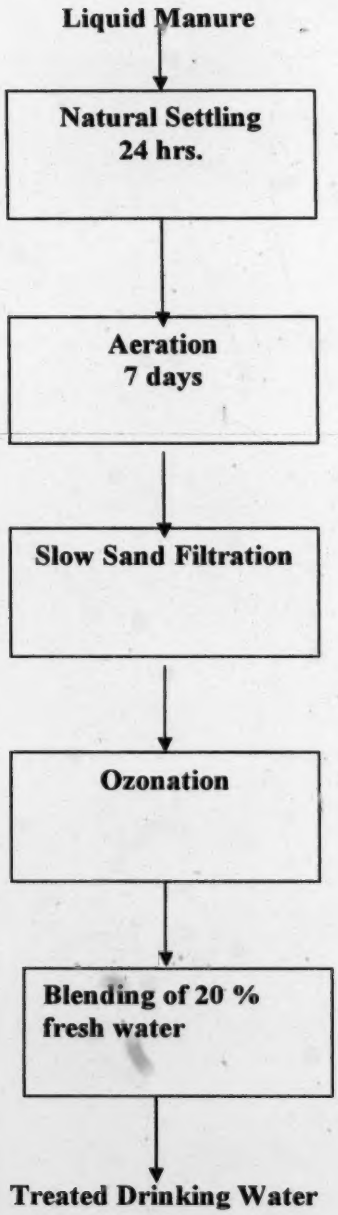

Figure 6.1 Schematic diagram of liquid manure water treatment scheme

Area for further Research

1) Pig response and performance to the treated liquid

Poor water quality would affect the pig feed intake and performance. Therefore, studying the response and performance may provide information needed for convincing the pork producers to use recycle drinking water for pigs

3) Performance and economics of a large scale experiment

Mechanical aeration in waste water treatment can be very energy intensive. The energy-cost estimated for providing drinking water for a facility with 300 growing pigs was $0.20 per growing pig. As aeration is a widespread waste management practice in various industries and provide some odour control, studying the performance of this large scale unit would be useful.

APPENDIX 1 TSS Values for Supernatant Liquid after Adding Alum, Lime and Gypsum and allowed 24 hrs for Settling.

Chemicals (mg/l)	Set1	Set2	Set3	Set4	Set5	Set6	Set7
Aluminum sulfate (250)	63	54	55	273	168	211	410
Aluminum sulfate (500)	41	82	70	320	141	77	390
Aluminum sulfate (250) & Gypsum (500)	294	54	192	172	55	116	470
Aluminum sulfate (250) & Gypsum (1000)	443	105	42		43	140	430
Lime (3000)	52	192	88	63	56		480
Lime (4500)	105	199	34	80	65		440
Lime (3000)& Gypsum (500)	174	150		80	65		500
Lime (4500) & Gypsum (1000)	88	243	104	175	158	364	540
Controls	140	191		100	42		500

APPENDIX 2 Chemical Parameters of Liquid Manure

Parameter	Sample 1 (mg/l)	Sample 2 (mg/l)
Chloride	285	287
Nitrite-Nitrate N	<0.1	<0.1
pH	7.1	7.4
Alkalinity	3180	3040
TDS	4100	4090
Hardness	318	377
Calcium	111	115
Potassium	387	323
Magnesium	9.9	32.7
Sodium	177	142
Sulfate	536	1040
TSS	2900	7300

APPENDIX 3 Chemical Parameters after Reverse Osmosis Filtration

Parameter	Sample 1 (mg/l)	Sample 2 (mg/l)
Chloride	115	132
Nitrite-Nitrate N	<0.1	<0.1
pH	7.5	7.5
Alkalinity	536	594
TDS	766	623
Hardness	12	26
Calcium	4	8.3
Potassium	74.6	84.1
Magnesium	0.6	1.3
Sodium	30	34
Sulfate	5.8	7.1

APPENDIX 4 RO Filtration Using Liquid Manure at Operating Pressure Range (207 – 278 kPa)

(3 Replicates)

No	Time (Min)	Out Volume (ml)	Out TDS (ppm)	Rej Volume (ml)
1	5	15	805	990
2	10	20	805	1000
3	15	20	805	950
4	20	20	805	960
5	25	20	1300	940
6	30	20	1300	940
7	35	20	1300	940
8	40	17	1300	950
9	45	17	1540	930
10	50	17	1540	940
1	5	30		1000
2	10	30		980
3	15	25		990
4	20	25		980
5	25	30	1320	1000
6	30	25	1320	970
7	35	30	1350	1100
8	40	25	1350	990
9	45	30	1600	990
10	50	25	1600	980
1	5	20		910
2	10	20		920
3	15	20	1300	880
4	20	20	1300	940
5	25	20	1660	930
6	30	20	1660	940
7	35	20	1710	920
8	40	20	1710	930
9	45	20	1770	920
10	50	20	1770	920

RO Filtration using liquid manure at operating pressure range (345 -414 kPa)

(3 Replicates)

No	Time (Min)	Out Volume (ml)	Out TDS (ppm)	Rej Volume (ml)
1	5	65		1220
2	10	60	585	1230
3	15	55	801	1200
4	20	55	693	1200
5	25	50		1300
6	30	55		1310
7	35	45	876	1370
8	40	45	861	1370
9	45	50	825	1370
10	50		801	1340
1	5	55	1100	1240
2	10	50	1140	1220
3	15	50	855	1230
4	20	50	839	1220
5	25	50	805	1230
6	30	50	810	1220
7	35	50	830	1220
8	40	50	832	1220
9	45	50	847	1220
10	50	50	837	1220
1	5	57	563	1220
2	10	55	704	1220
3	15	55	740	1230
4	20	55	790	1220
5	25	50	784	1240
6	30	50	823	1210
7	35	47	831	1220
8	40	47	835	1200
9	45	50	847	1220
10	50	50	825	1200

RO Filtration using tap water at operating pressure range

(207 - 278 kPa)

(3 Replicates)

No	Time (Min)	Out Volume (ml)	Out TDS (ppm)	Rej Volume (ml)
1	5	175	13	815
2	10	165	13	850
3	15	165	13	810
4	20	165	10	800
5	25	165	11	800
6	30	165	8	780
7	35	170	8	780
8	40	170	11	775
9	45	170	11	760
10	50	160	11	765
1	5	175	13	815
2	10	165	13	850
3	15	165	13	810
4	20	165	10	800
5	25	165	11	800
6	30	165	8	780
7	35	170	8	780
8	40	170	11	775
9	45	170	11	760
10	50	160	11	765
1	5	197	6	960
2	10	195	9	970
3	15	197	9	960
4	20	197	5	960
5	25	195	8	950
6	30	197	7	960
7	35	197	7	950
8	40	197	9	950
9	45	195	8	950
10	50	205	14	940

RO Filtration using tap water at operating pressure range

(345 -414 kPa)

(3 Replicates)

No	Time (Min)	Out Volume (ml)	Out TDS (ppm)	Rej Volume (ml)
1	5	360	6	1310
2	10	340	5	1270
3	15	340	5	1310
4	20	325	7	1260
5	25	315	6	1260
6	30	310	6	1250
7	35	315	6	1270
8	40	315	5	1250
9	45	310	6	1260
10	50	305	7	1240
1	5	330	4	1240
2	10	315	6	1260
3	15	300	5	1220
4	20	300	5	1240
5	25	300	4	1220
6	30	305	6	1230
7	35	310	4	1230
8	40	300	6	1230
9	45	315	7	1240
10	50	356	7	1300
1	5	330	4	1240
2	10	315	6	1260
3	15	300	5	1220
4	20	300	5	1240
5	25	300	4	1220
6	30	305	6	1230
7	35	310	4	1230
8	40	300	6	1230
9	45	315	7	1240
10	50	356	7	1300

APPENDIX 5 Aeration, Ozonation and Natural Settling (Replicate 1)

(TDS in mg/l)

Days	Aeration1 rate 1	Aeration Rate 2	Ozone	Natural settling
1	6750	6760	6780	6700
1	6750	6780	6800	6710
2	5450	5200	5510	6600
2	5460	5220	5500	6610
3	5120	4510	5200	6420
3	5140	4540	5190	6400
4	4770	4270	5090	6250
4	4780	4280	5080	6270
5	4420	4080	4850	5890
5	4430	4080	4870	5900
6	4220	3780	4820	5760
6	4230	3800	4830	5780
7	3970	3690	4380	5600
7	3980	3680	4360	5600
8	3750	3520	4160	5460
8	3770	3540	4170	5470
9	3750	3470	4110	5400
9	3740	3480	4120	5410
10	3710	3610	4090	5260
10	3720	3620	4100	5270
11	3740	3530	4060	5290
11	3750	3540	4090	5300
12	3640	3420	3940	5340
12	3640	3430	3950	5330
13	3500	3190	3820	5320
13	3510	3210	3830	5310
14	3480	3280	3990	5230
14	3470	3290	3950	5240
16	3380	3220	4010	5280
16	3390	3240	4090	5290
18	3270	3160	4230	5200
18	3300	3170	4240	5210

Aeration, Ozonation and Natural Settling (Replicate 2)

(TDS in mg/l)

Days	Aeration Rate 1	Aeration Rate 2	ozone	Natural settling
1	6250	6230	6380	6350
1	6250	6240	6400	6400
2	5470	5180	5850	6250
2	5480	5200	5840	6270
3	5150	4650	5630	6230
3	5170	4670	5620	6250
4	4700	4380	5470	6050
4	4710	4400	5480	6070
5	4600	4130	5330	6140
5	4590	4150	5340	6100
6	4350	3880	5070	6000
6	4360	3890	5080	6010
7	3900	3490	5120	6070
7	3910	3500	5140	6080
8	3850	3680	4720	5950
8	3820	3690	4740	5960
9	3550	3450	4670	5940
9	3540	3440	4670	5950
10	3390	3240	4460	5870
10	3400	3250	4470	5890
11	3320	3270	4330	5820
11	3330	3260	4340	5810
12	3320	3200	4270	5730
12	3310	3210	4270	5740
13	3380	3200	4100	5730
13	3370	3210	4120	5740
14	3410	3170	4030	5440
14	3420	3170	4040	5450
16	3520	3200	4090	5390
16	3530	3220	4050	5400
18	3660	3390	4090	5400
18	3670	3400	4050	5390

APPENDIX 6 Aerated Liquid Manure Chemical Parameters

Parameter	Liquid Manure	Aerated liquid manure	Standards	Detection Limits
pH	7.6	**8.7**	6.5 to 8.5	0.1
TDS (mg/l)	**6500**	**3475**	3000	1%
Alkalinity (mg/l)	**5130**	1140	5000	5
Hardness (mg/l)	413	79	N/A	
Calcium (mg/l)	129	25.9	1000	0.5
Sodium (mg/l)	317	362	500	1
Sulfate (mg/l)	**1150**	**791**	750	0.5
Nitrite-Nitrate N (mg/l)	1.5	1.8	100	0.1
Iron (mg/l)	**4.41**	**2.42**	0.3	0.005
Aluminum (mg/l)	1.13	0.4	5.0	0.01
Arsenic (mg/l)	0.0310	0.0326	0.5	0.0004
Berylium (mg/l)	<0.0002	<0.0002	0.1	0.002
Boron (mg/l)	1.19	1.23	5.0	0.05
Cadmium (mg/l)	0.001	0.002	0.02	0.001
Lead (mg/l)		0.006	0.1	0.005
Nickel (mg/l)	0.082	0.13	1.0	0.002
Zinc (mg/l)	2.57	0.861	50	0.001
Total Suspended Solids	5100	82		3

APPENDIX 7 Pathogen Count After Aeration and Filtration

PATHOGENS	SAMPLE 1	SAMPLE 2
Total coliform (MPN/100 ml)	23	0
Fecal coliform (MPN/100 ml)	23	0
Escheria.coli (MPN/100 ml)	23	-
Salmonella (MPN/100 ml)	Not identified	

APPENDIX 8 Edmonton Drinking Water Parameter

Parameter	2002 Median
pH	7.8
Alkalinity (mg/l)	116
TDS (mg/l)	210
Calcium (mg/l)	110
Hardness (mg/l)	160
Sodium (mg/l)	11
Sulfate (mg/l)	67
Nitrate (mg/l)	<0.001

APPENDIX 9 SAS PROGRAMS

Program 1 Settling

```
data settling;
input treat set TSS;
cards;
1       1       63
2       1       41
3       1       294
.....
;
proc glm;
class treat set;
model TSS= treat set/ss3;
mean treat /snk;
run;
```

Program 2 Reverse Osmosis

```
data osmosis;
input pressure time outvol outtds rejvol rejtds;
cards;
1    5    175   13   815   220   1    1    175   815
1    10   165   13   850   223   1    1    165   850
1    15   165   13   810   221   1    1    165   810
1    20   165   10   800   225   1    1    165   800
.....
.....

run;
proc  print;
run;
proc glm;
class pressure source time;
model outvol  = pressure source pressure*source
        time time*pressure time*source time*pressure*source/ss3;
 lsmeans  pressure*source/stderr pdiff;
        run;

 proc glm;
```

```
class pressure source time;
model  outtds  = pressure source pressure*source
        time time*pressure time*source time*pressure*source/ss3;
 lsmeans  pressure*source*time pressure*source/stderr pdiff;
        run;

 proc glm;
class pressure source time;
model  rejvol  = pressure source pressure*source
        time time*pressure time*source time*pressure*source/ss3;
 lsmeans  pressure*source/stderr pdiff;
        run;
```

Program 3. Aeration

```
data aeration;
input treat period block tds;
cards;
1    1    1    6750
1    1    1    6750
1    2    1    5450
1    2    1    5460
.....
run;

proc glm;
class treat period block;
model tds=treat block treat*block period period*treat/ss3;
test h = treat block e=Treat*block/etype=3 htype=3;
lsmeans treat/e=treat*block stderr pdiff;
lsmeans treat*period/stderr pdiff ;
run;
```